DOT/FAA/AR-95/112

Office of Aviation Research
Washington, D.C. 20591

Transport Water Impact, Part II

May 1996

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-95/112		

4. Title and Subtitle TRANSPORT WATER IMPACT, PART II	5. Report Date May 1996
	6. Performing Organization Code
7. Author(s) Jagdeep M. Tahliani and Mark Muller	8. Performing Organization Report No.
9. Performing Organization Name and Address Galaxy Scientific Corporation 2500 English Creek Avenue, Building 11 Egg Harbor Township, NJ 08234-5562	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTFA03-89-C-00043
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research Washington, DC 20591	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code AAR-431

15. Supplementary Notes

Robert J. McGuire—William J. Hughes Technical Center Contract Monitor
Gary Frings—William J. Hughes Technical Center Program Manager

16. Abstract

This report documents the second of a two-part program intended to study the over-water operating environment of jet transport aircraft. The report is comprised of three sections: aircraft accident analysis, airport water rescue, and emergency flotation devices. Worldwide transport airplane accident data from 1959 to the present were reviewed with an emphasis on water impact accidents and land impact accidents that occurred near airports. A sample of these land impact accidents were analyzed, using a mathematical model, to predict their outcome had they impacted a body of water. Water rescue programs at 23 national airports were surveyed addressing facilities, equipment, personnel, operations, and the airport water environment. New water rescue techniques and equipment were examined. A study of current federal regulations and NTSB recommendations regarding airport water rescue was performed. Personal flotation devices (PFDs), seat cushions, life preservers, life rafts, evacuation slides, and slide-raft combinations carried on commercial transport aircraft were studied. Relevant Federal Aviation Regulation (FARs) and Technical Standard Orders (TSOs) were reviewed. Recommendations on improving the existing regulations and incorporating new features into the devices to improve performance and reliability of the devices are discussed.

17. Key Words	18. Distribution Statement
Water impact, Flotation equipment, Regulations, Ditching, Water rescue, Airports, Personal flotation devices, Life rafts, Survivability, Technical Standard Orders	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	114	

Form DOT F1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AAIB	Air Accident Investigation Board
AC	Advisory Circular
AEP	Airport Emergency Plan
ARFF	Aircraft Rescue and Firefighting
C	Celsius
CAA	Civil Aviation Authority
CAMI	The Civil AeroMedical Institute
CFR	Crash, Fire, and Rescue
DOT	Department of Transportation
ELT	Emergency Locator Transmitter
EOO	Extended Over-Water Operations
EPIRB	Emergency Position Indication Radio Beacon
F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
ft.	foot/feet
GPM	Gallons Per Minute
GSC	Galaxy Scientific Corporation
ICAO	International Civil Aviation Organization
in.	Inches
lb.	Pound
mil	one-thousandth of one inch
MIL-STD	Military Standard
NTSB	National Transportation Safety Board
PFD	Personal Flotation Device
psig	Pounds Per Square Inch Gauge
RIV	Rapid Intervention Vehicles
SAR	Search and Rescue
TSO	Technical Standard Orders

EXECUTIVE SUMMARY

This report documents part II of a program to study the over-water operating environment of jet transport aircraft. The report is comprised of three sections; aircraft accident analysis, airport water rescue, and emergency flotation devices.

SECTION 1. AIRCRAFT ACCIDENT DATA ANALYSIS.

Selected land accidents were placed in a hypothetical analysis to predict their outcome had they impacted a body of water. A mathematical model was used to capture the relative importance of various survival factors in water impact accidents. Two impact scenarios were identified, surface to ground (ditching) and runway overrun. Conclusions from the model were as follows:

- The fatality rate for ditching accidents was 44 percent and for runway overruns was 10.1 percent.
- Drowning was the major cause of death in water impacts in both ditching and overrun scenarios.
- Postcrash fires, deaths due to asphyxia, smoke inhalation, and thermal injuries were the major postimpact hazards in land accidents in contrast to drowning from entrapment, flotation device performance, and post evacuation exposure in water impacts.
- Postimpact fatalities were almost two and a half times higher in water accidents than in land accidents. However, there was a greater number of impact fatalities in land accidents.

SECTION 2. AIRPORT WATER RESCUE.

A survey of water rescue facilities, equipment, personnel, and operations at twenty-three domestic airports was accomplished. Key results from the survey are:

- Larger airports were more likely to have on-site water rescue capabilities. Among airports surveyed, 75 percent of large, 43 percent of medium, and 25 percent of small airports had on-site water rescue capability.
- Airports immediately adjacent to bodies of water were more likely to have water rescue capabilities than those located within 5 miles of water.
- Airports that had provisions to keep rescue vessels docked in the water had a significantly lower response time than airports that do not have such provisions.
- Different types of water bodies have unique water rescue requirements. The type of water rescue vessels, equipment, and the training of water rescue personnel should be based on

several factors typical to the airport's water environment, including the type of water body, the temperature, and the depth of the water body.

- The number, type, and capabilities of water rescue vessels in the fleet as well as the water rescue equipment, personnel, and training may vary greatly from airport to airport.
- There are no regulations that require airports to operate and maintain facilities, equipment, and personnel dedicated to water rescue situations.
- No standardized requirements are in place for the number, quantity, or type of water rescue vessels and equipment.

SECTION 3. EMERGENCY FLOTATION DEVICES.

The regulations pertaining to the design, certification, and use of onboard emergency flotation devices including seat cushions, life preservers, life rafts, and evacuation slides were studied. A technology survey of commercially available devices was also accomplished. The results of the study are as follows:

- The hazard of hypothermia from water immersion is a major concern in aircraft water impact. Emergency flotation devices are essential to reducing this hazard.
- Flotation devices are designed to meet the minimum requirements for TSO approval. Additional enhancements or performance characteristics are typically not incorporated above and beyond the TSO specifications.
- Advanced infant life preservers that provide hypothermia protection are currently available. These preservers use an advanced thermal capsule design.
- The use of TSO C-13 life preservers in place of the comparatively inferior TSO C-72 is desirable in all aircraft. Improved designs should incorporate increased protection from hypothermia.
- Although the performance of flotation seat cushions has been debated, they are still highly essential on all aircraft. In unplanned water accidents, they are likely to be the only available means of flotation.
- The stowage location, retrievability, and ease of unpacking and donning still remain the main causes of concern for inflatable personal flotation devices (PFDs) and life preservers.
- Basic regulatory amendments to improve field testing and demonstration of PFDs were identified.
- Review of flotation equipment indicates that raft stability, canopy design, packaging valise, and stowage location may be improved.

SECTION 1. ACCIDENT DATA ANALYSIS

INTRODUCTION.

A previous study [1] examined worldwide transport airplane accident data and focused on water impacts. The study identified accidents and discussed issues that might impact the survivability of transport aircraft accidents involving water. The analysis considered accidents during the period from 1959 to 1994. Eleven accidents involving water were identified between the years 1959 and 1979, only one of which was defined as a ditching occurrence. Since 1979, only four U.S. water-related accidents were identified, none of which was considered to qualify as a ditching.

These findings indicated that very little water impact accident data are available for analyses. During the review of water impact accidents for the present study, several instances were noted where water impacts were unsurvivable due to breakup of the fuselage and rapid sinking with all the occupants trapped inside. Efforts to locate and extricate the fuselage from deep water were considered unfeasible, and therefore the flight data recorder (FDR) was never recovered nor was the wreckage examined for clues as to the cause and conditions of the impact.

An earlier study on transport water impact [2] concluded that "the operating conditions and circumstances leading to a ground or water impact occurrence are generally equivalent." It is perhaps by chance that relatively few accidents (11 out of 153 in reference 2) to date have involved water, and although the number of accidents is small, the potential for water accidents is high. Previous studies [1, 2, and 3] showed that most of the accidents involving water occurred in close proximity to airports during the landing or takeoff phase of flight.

Because most previous water accidents occurred near airports and because of the lack of existing water accident data, it was a goal of this study to consider scenarios where land accidents could have occurred in the water, had a body of water been present. More specifically, land accidents that occurred close to airports were assumed to occur in water and aircraft damage and occupant survivability were predicted. To support this analysis, data from various sources were used. A database of 11 water accident reports among the National Transportation Safety Board (NTSB) safety studies, recent water impact studies, as well as research from sections 2 and 3 of this study on airport water rescue and personal flotation devices (PFDs) respectively.

An analysis was performed to predict the outcome of the hypothetical water impacts, including the level and type of impact damage to the aircraft structure, the estimated time afloat, the time required for evacuation, the number of evacuees, and postimpact survivability. The analyses also led to estimates of the number of survivors and the cause and number of fatalities. The analysis was based on a mathematical model that relied on several inputs from the land accidents. Accident parameters such as aircraft weight, speed and attitude at impact, the prevalent weather conditions, and time of day were taken from the actual land accident. In addition, the predicted effectiveness of the crew, the reliability of PFDs, the level of occupant preparedness prior to the accident, the depth and temperature of the water, and the level of injuries to passengers were all factored into the model.

A review of water accidents to date indicated that they predominantly fell into two categories. In the first category are those that occurred while the aircraft was on approach and the aircraft was ditched in the water, either unintentionally or intentionally (i.e., air to ground). In the second category are those that occurred due to runway overruns, either in the takeoff or the landing phase (i.e., surface to surface). These are considered as two distinct classes of water impacts due to the different conditions prior to and after the accident. The land accidents studied in this report were also similarly categorized, and the resulting inputs to the model arose primarily from this categorization.

The Federal Aviation Administration (FAA) describes ditchings as a controlled emergency descent into the water, generally implying some level of preparation prior to the accident. In this report, the term "ditching" is modified to indicate accidents where an airborne aircraft crashes into the water, regardless of the level of preparation. Nevertheless, the level of preparation prior to the accident is an important factor, and this is accounted for by identifying these ditching accidents as either planned or unplanned. The other class of water impacts involves aircraft that were never airborne prior to their impact with water, and these are referred to as overruns, which can occur at takeoff or landing.

BACKGROUND.

There are fundamental differences between accidents that occur in the water and those that occur on land. This section compares airframe crash performance and survivability factors that affect occupants in accidents in both types of scenarios. This section provides background information for the accident analyses that were performed where the outcome of land accidents was predicted for water impact. Reference 2 concluded from a preliminary analysis that in general, unplanned water contact "leads to higher impact loads and greater fuselage damage than corresponding ground contact."

AIRFRAME CRASH PERFORMANCE. The response of an aircraft structure to ground impact and water impact is quite different. In a ground impact, the load is transferred from the ground through the frame and other rigid structural airframe elements. The crushable structure absorbs energy from the vertical crash component. The sliding friction dissipates longitudinal crash forces, provided there are no obstacles or ground grades to break up the airframe. Soft ground impact is somewhat akin to water impact in that the decelerative loads can greatly increase if scooping or plowing occurs.

In a water impact, the load is distributed across the airframe's outer surface as a hydrodynamic pressure. Also, any protuberances will act to scoop water, creating decelerative drag loads. If the hydrodynamic pressure is sufficient to cause localized rupture of the airframe's skin, then the damage is likely to progress rapidly because of submergence and the resulting drag force exerted on the structure. Such damage mechanisms, different from those on rigid ground, not only tend to increase the deceleration experienced by occupants but also reduce the buoyancy of the aircraft, thereby increasing the postimpact hazard to the occupants. These postimpact hazards can be in the form of evacuation difficulties and the risk of drowning. The sea state can also

affect the damage experienced by an aircraft impacting water. It is beneficial for example, to land parallel to, not across the line of wave crests.

OCCUPANT SURVIVABILITY. One of the main differences between water and land impacts is the different postcrash environment that the survivor will face. In ground accidents, the need to evacuate the aircraft to avoid potential cabin fire is the immediate concern. Quick egress is also a priority for the water accident victim, but it is usually done to escape a sinking fuselage. Both situations are extremely hazardous and are primarily governed by the type and severity of the damage sustained by the aircraft during impact. In the case of a water accident, however, further postcrash hazards can arise that play an important role in survivability. These additional hazards exist in the time immediately after the impact, during the evacuation, as well as in the postcrash environment and are discussed in this section.

In a water accident, survivors have the additional responsibilities of having to locate and don PFDs, to assist infants and elderly in doing the same, followed by successfully locating, deploying, and using rafts or slide-rafts as available. There are instances where these devices may not be available, as was seen in the May 1978 accident involving the unplanned ditching of a Boeing 727 near Pensacola, Florida. Hence the reliance on auxiliary equipment for postcrash survival adds another dimension to postcrash survivability that is not present in land accidents. The postcrash water environment demonstrated the importance of the availability, ease of use, and reliability of water survival equipment. See section 3 of this study for more on water survival equipment.

After having successfully completed the evacuation procedure, the survivor is then faced with an entirely new set of hazards. These can include the threat of hypothermia and drowning, the presence of debris and perhaps fuel or chemicals in the water, the threat of inclement weather and water conditions, the presence of dangerous marine life, and the continued reliance on personal flotation devices and rafts. There is also the need for prompt response from crash, fire, and rescue (CFR) personnel and services. See section 2 of this study for more on airport water rescue.

At the outset, occupant survival in water impacts seems to be more influenced by the performance of other subsystems, weather conditions, and search and rescue (SAR) services than equivalent land accidents. Hence, it may be expected that in the face of these hazards, the number of postcrash survivors is lower in water impacts than in equivalent ground impacts.

APPROACH.

Several organizations were contacted in order to obtain detailed accounts of accidents for inclusion in the present study. The various sources used for the water impact accident data as well as the accident selection criteria for study in the present analysis are given in the following section.

DATA SOURCES. Selected water impact accident occurrences were assembled as a database. This water impact database was used extensively for predicting the results of land accidents had they occurred in the water.

Water Impact Accidents (1959-Present). Transport aircraft accidents that occurred in the period from 1959 to 1979 were identified and examined in three independent studies conducted by major airframe manufacturers [4, 5, and 6]. Data for the reports came from a variety of sources including FAA/Civil Aeronautics Board (CAB) reports, NTSB reports, and information released by foreign governments, organizations, airlines, and aircraft manufacturers. A specific analysis relative to water impacts in this period was subsequently done in reference 2 and was based primarily on the manufacturer reports just mentioned. This study identified 11 accidents out of a total of 153 cases in which water played an important role. Of the 11 accidents, five occurred in the United States or its territories. These five accidents were analyzed in detailed CAB/FAA reports, and four of these reports were retrieved for the present study to form part of the database of water impacts. In addition, two more accidents that were not identified in any of these reports were identified in the present study. The first was a 1963 accident involving a DC-7C operating as a military charter flight that was intentionally ditched in Sitka Sound, Alaska. The other was a DC-8 that was operating as a commercial flight from Japan to San Francisco. The aircraft was unintentionally ditched in the San Francisco bay, less than three miles from the airport.

For the period from 1980 to 1991, reference 1 identified 19 additional water impacts, including those that were classified as unsurvivable. Of these, only five occurred within the U.S. or its territorial waters, and hence detailed accident reports were available through the NTSB. From 1991 to the present, one more domestic water impact was identified, involving a Fokker F-28 overrun at La Guardia Airport, New York.

Hence, in the cumulative period from 1959 to the present, a total of 31 water impacts were identified. Excluding nonsurvivable accidents, accidents in foreign jurisdictions, and accidents for which detailed reports were not available, the number used for setting up the water impact database equaled a total of 11 accidents. These 11 accidents are listed table 1.

TABLE 1. WATER IMPACTS FROM 1959 TO 1995 INCLUDED IN DATABASE

	Date	Aircraft	Operator	Location	Type of Impact
1	03/22/92	F-28	US Air	LGA A/P, New York	Takeoff Overrun
2	09/20/89	B 737	US Air	LGA A/P, New York	Takeoff Overrun
3	06/27/85	DC-10	American	SJU A/P, Puerto Rico	Takeoff Overrun
4	02/20/84	DC-10	Scandinavian	JFK A/P, New York	Landing Overrun
5	01/23/82	DC-10	World Airways	BOS A/P, Boston	Landing Overrun
6	05/08/78	B 727	National Air	Pensacola Bay, FL	Unplanned Ditching
7	05/02/70	DC-9	Overseas National	St. Croix, Virgin Islands	Planned Ditching
8	11/22/69	DC-8	Japan Airlines	San Francisco Bay, CA	Unplanned Ditching

TABLE 1. WATER IMPACTS FROM 1959 TO 1995 INCLUDED IN DATABASE
(Continued)

	Date	Aircraft	Operator	Location	Type of Impact
9	01/13/69	DC-8	Scandinavian	Santa Monica Bay, CA	Unplanned Ditching
10	04/07/64	B 707	Pan Am	JFK A/P, New York	Landing Overrun
11	10/22/63	DC-7C	Northwest Airlines	Sitka Sound, Alaska	Planned Ditching

Figure 1 summarizes the distribution of the water impact accidents in terms of overruns or ditchings. Overruns are further categorized by the phase of operation, and ditchings are classified as planned or unplanned.

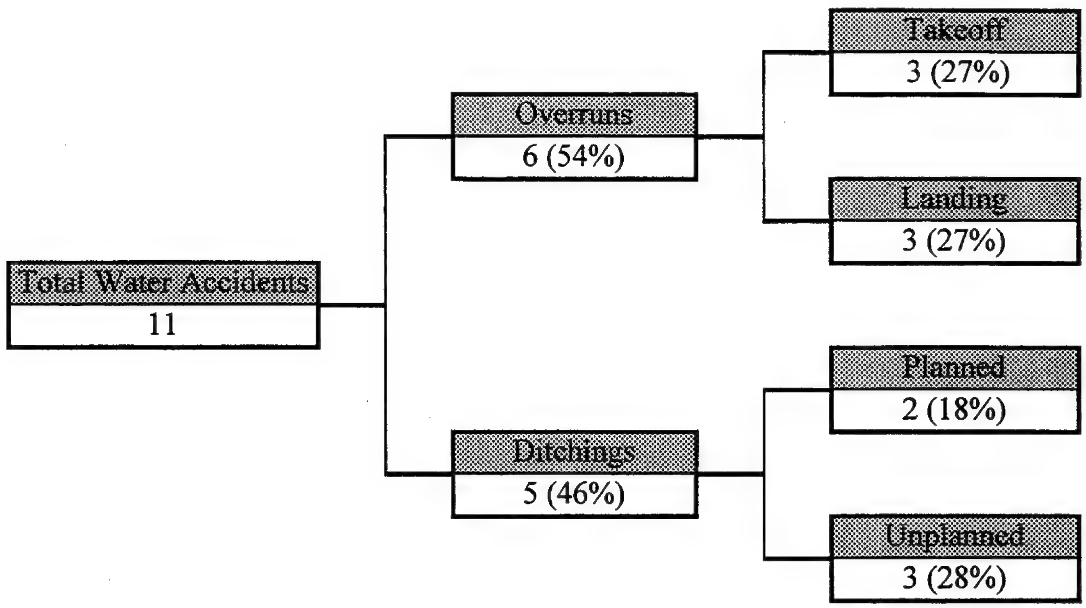


FIGURE 1. TYPE AND CATEGORY OF WATER IMPACT ACCIDENTS INCLUDED IN DATABASE

Land Accidents. As in the water impact cases, the land accidents from 1959 to 1979 were identified in references 4, 5, and 6. For the period from 1980 to the present, an extensive search was performed to identify accidents that occurred on or in the vicinity of airports during either the approach, takeoff, climb, or landing phase of the flight. In reference 2, an analysis was performed on airport vicinity accidents that would have resulted in water impact, had water been present. It was found that almost 80 percent of the accidents occurred during the approach, landing, takeoff, and climb phases of operation, all of which are always accomplished close to an airport.

A search of Civil Aviation Authority (CAA) databases identified 289 ground/water transport aircraft accidents throughout the world between 1981 to 1994. Additional sources for accident data were identified as International Civil Aviation Organization (ICAO), the NTSB,

and the Air Accident Investigation Board (AAIB). The results of the search are presented in table 2.

TABLE 2. WORLDWIDE LAND ACCIDENTS FROM 1981 TO 1994, WITH DISTRIBUTION OF SOURCES

Accident Data					Sources				
Year	Total	Runway Veeroffs	Non-survivable	Net Accidents	ICAO	NTSB	AAIB	Other	None
1980	18	5	2	11	2	1	0	0	8
1981	18	9	1	8	2	0	0	1	5
1982	24	3	6	15	7	2	0	1	5
1983	18	5	5	8	4	0	0	1	3
1984	11	7	1	3	1	0	0	0	2
1985	24	6	7	11	6	1	1	0	3
1986	21	3	3	15	6	2	0	2	5
1987	15	2	3	10	4	2	0	3	1
1988	25	6	3	16	4	1	1	5	5
1989	26	4	2	20	5	0	1	3	11
1990	23	2	2	19	4	1	0	1	13
1991	12	0	2	10	1	1	0	1	7
1992	13	0	3	10	0	0	0	0	10
1993	24	0	2	22	0	0	0	1	21
1994	17	0	5	12	0	0	0	0	12
Total	289	52	47	190	46	11	3	19	111

Of the 289 accidents identified, those that were considered nonsurvivable or those where the aircraft simply veered off the runway were deducted. In the latter case, the aircraft typically ends up on airport property and therefore the potential for water impact does not exist. This left a total of 190 accidents where the presence of water at impact could be hypothesized. The CAA indicated that no sources exist for 111 of these 190 accidents, leaving 79 accidents for analysis. The final number of accidents used for analysis in the present study were restricted by another set of conditions which are outlined in the following section.

LAND ACCIDENT SELECTION. The primary objective of the analysis was to investigate accidents which did not occur in water, yet had they occurred at an airport located adjacent to a body of water, could have resulted in a water impact. Therefore, the following criteria were imposed:

- The accident must have involved a passenger flight, (Scheduled or nonscheduled).

- The accident must have occurred as a result of one of the following scenarios: runway overrun, either at takeoff or landing; runway undershoot at landing; or forced landing near the airport during either takeoff, initial climb, approach or landing.

Nonsurvivability was removed as a criteria for exclusion from the study. It was an objective to hypothesize the outcome of the accident had it occurred in the water, and survivability of the water impact should not be determined based on survivability of the ground impact. Also, due to the unavailability of many of the reports that met these criteria, the final number of accidents that were analyzed was limited to those for which detailed reports could be obtained which would permit a thorough investigation of the relevant parameters. Requests for detailed accident data from the various organizations mentioned in the previous section were successful in some cases; however, the level of detail required for the present study was only found in NTSB reports.

Twenty accidents were finally selected and are listed chronologically in table 3. The table also shows the airport in the vicinity of the accident. The last column of the table shows the classification of the accident had the aircraft impacted water. The four categories are overrun at landing, overrun at takeoff, planned ditching, and unplanned ditching.

The first two scenarios are most likely if the aircraft never leaves the ground. The unplanned ditching scenario is the most likely scenario if the aircraft crashes in the vicinity of the airport during approach or landing. This situation is classified as a planned ditching if the crew had some knowledge that they were going to crash, thereby allowing for some prior preparation. This is a crucial factor for survivability in all accidents but more so in water impacts since it affords the chance to locate and don personal flotation devices and prepare the cabin for impact.

The categories of accidents within the twenty selected land accidents are shown in figure 2.

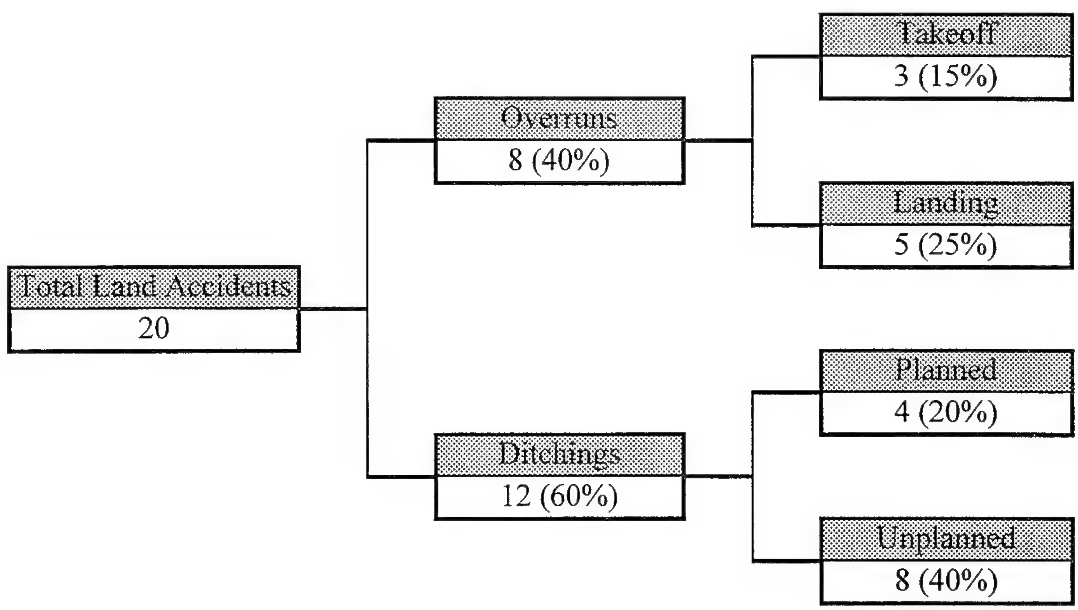


FIGURE 2. PREDICTED WATER IMPACTS SCENARIOS FOR THE SELECTED LAND ACCIDENTS

TABLE 3. LAND ACCIDENTS SELECTED FOR ANALYSIS, SHOWING ACCIDENT LOCATION AND PREDICTED WATER IMPACT SCENARIO

	Date	Aircraft	Operator	Location	Airport	Description	Predicted Water Impact Scenario
1	06/23/76	DC-9-31	Allegheny	Philadelphia, PA	Philadelphia International	Landing Overrun	Landing Overrun
2	11/16/76	DC-9-14	Texas International	Denver, CO	Denver Stapleton	RTO Overrun	Takeoff Overrun
3	04/04/77	DC-9-31	Southern Airways	New Hope, GA	—	Crash on Road	Planned Ditching
4	03/01/78	DC-10-10	Continental	Los Angeles, CA	Los Angeles International	RTO Overrun	Takeoff Overrun
5	12/28/78	DC-8-61	United	Portland, OR	Portland International	Crash on Approach	Planned Ditching
6	02/17/81	B737-293	Air California	Santa Ana, CA	John Wayne Orange County	Crash on Landing	Unplanned Ditching
7	01/09/83	Convair 580	Republic Airlines	Brainerd, MN	Brainerd Airport	Landing Overrun	Landing Overrun
8	10/25/83	DC-8-63	Flying Tigers	Norfolk, VA	Chambers Field, NAS	Landing Overrun	Landing Overrun
9	06/13/84	DC-9-31	US Air	Detroit, MI	Detroit Metropolitan	Landing Overrun	Landing Overrun
10	01/21/85	L-188C	Galaxy	Reno, NV	Reno-Cannon International	Crash after Takeoff	Planned Ditching
11	08/02/85	L-1011	Delta	Dallas, TX	Dallas Fort Worth	Crash on Approach	Unplanned Ditching
12	09/06/85	DC-9-14	MidWest Express	Milwaukee, WI	General Billy Mitchel Airfield	Crash after Takeoff	Unplanned Ditching
13	10/26/86	B737-222	Piedmont	Charlotte, NC	Charlotte-Douglas International	Landing Overrun	Landing Overrun
14	08/16/87	DC-9-82	Northwest	Romulus, MI	Detroit Metro Wayne County	Crash after Takeoff	Unplanned Ditching
15	11/15/87	DC-9-14	Continental	Denver, CO	Denver Stapleton	Crash after Takeoff	Unplanned Ditching
16	04/15/88	DHC-8	Horizon Air	Seattle, WA	Seattle-Tacoma International	Crash on Approach	Unplanned Ditching
17	08/31/88	B727-232	Delta	Dallas, TX	Dallas Fort Worth	Crash after Takeoff	Unplanned Ditching
18	07/19/89	DC-10-10	United	Sioux City, IA	Sioux Gateway Airport	Crash on Approach	Planned Ditching
19	07/19/89	B707-321	Avianca	New York, NY	John F. Kennedy International	Crash on Approach	Unplanned Ditching
20	07/30/92	L-1011	Trans World	New York, NY	John F. Kennedy International	RTO Overrun	Takeoff Overrun

A comparison of figures 1 and 2 shows that the number of actual water ditchings (46 percent) are lower than the number of hypothetical ditchings (60 percent). However, the ratio between planned and unplanned ditchings for actual water impacts versus the hypothetical water impacts are quite similar. Planned ditchings account for 40 percent of the total ditchings in actual water impacts, and 33 percent of the total ditchings in the hypothetical water accidents.

ANALYSIS.

This section describes the mathematical model used to predict the outcome of actual land accidents had they occurred in the water. The parameters that are used for input to the model are described. It should be noted that the input parameters are by no means exhaustive in accounting for all the factors that influence the final outcome of an accident. Nevertheless, an effort was made to incorporate the most influential factors. It is an objective of the model to identify the various relevant factors in water impact and evaluate the effect they have on the predicted outcome.

Each of the twenty land accidents were analyzed to predict the outcome of a hypothetical water impact. Figure 3 shows the sequence and components of this analysis. The main sections of the model are aircraft impact damage, aircraft time afloat, evacuation time, and postevacuation survivability.

AIRCRAFT IMPACT DAMAGE. The damage sustained by the aircraft at impact is perhaps the single most important factor in a water impact. Reference 2 classified damage based on two levels of impact severity: high impact and slide/roll. Instead of using just two damage levels, a quantity called the damage factor, which was allowed to vary from 0 to 1 based on the severity of the impact, was used in the present study. Figure 4 defines the damage factor as a function of the extent of structural damage to the aircraft.

To prescribe a particular damage factor to a given land accident, certain criteria for impact severity had to be established. These criteria were based on the impact conditions of the land accident and were determined independently for the scenarios of ditchings and overruns.

For the ditching scenario, impact damage sustained in the five ditching accidents in the water accidents database (table 1) are shown in table 4. The speed and pitch angle at the time of the impact are given.

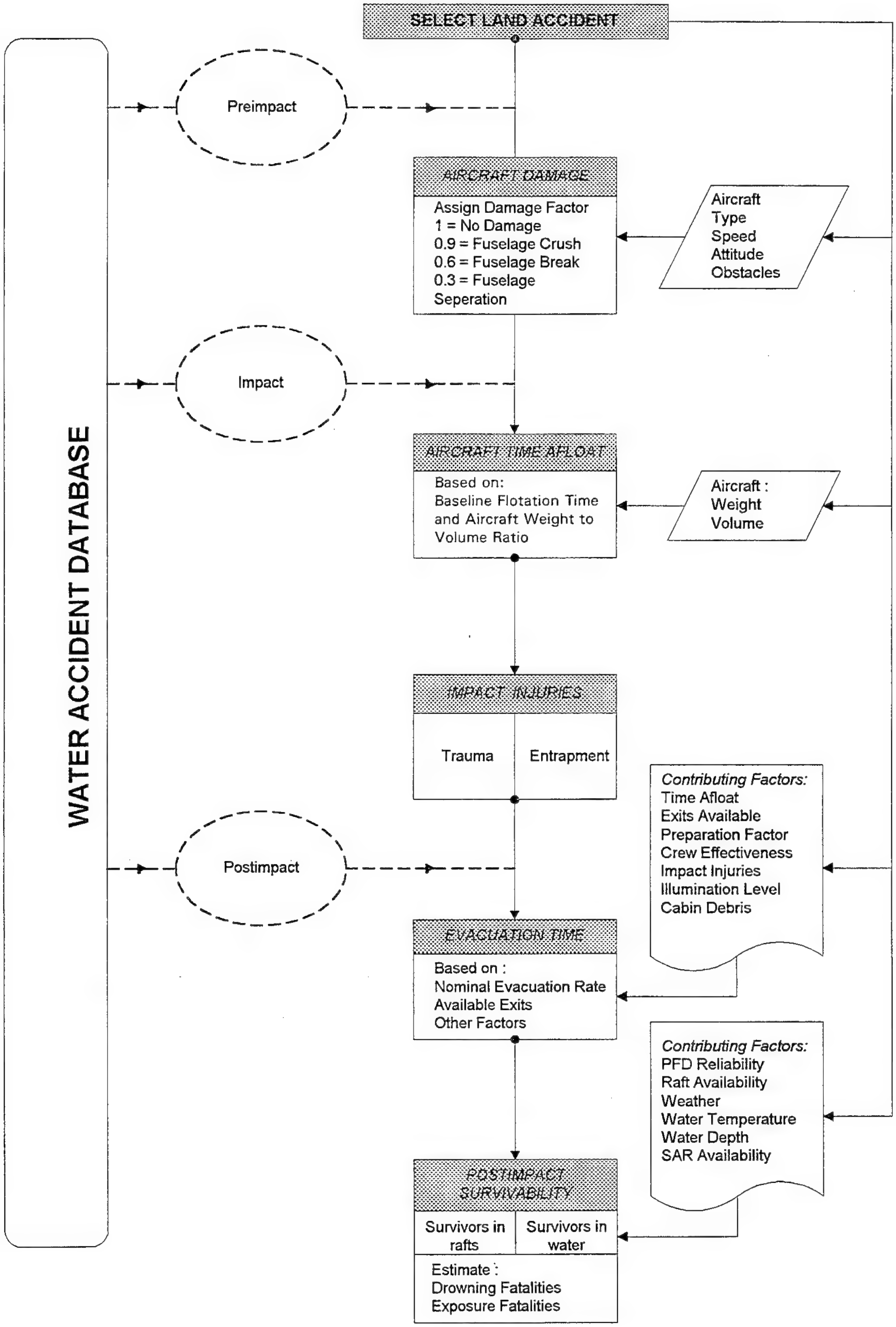


FIGURE 3. COMPONENTS OF ANALYSIS MODEL FOR LAND ACCIDENTS IN HYPOTHETICAL WATER IMPACT

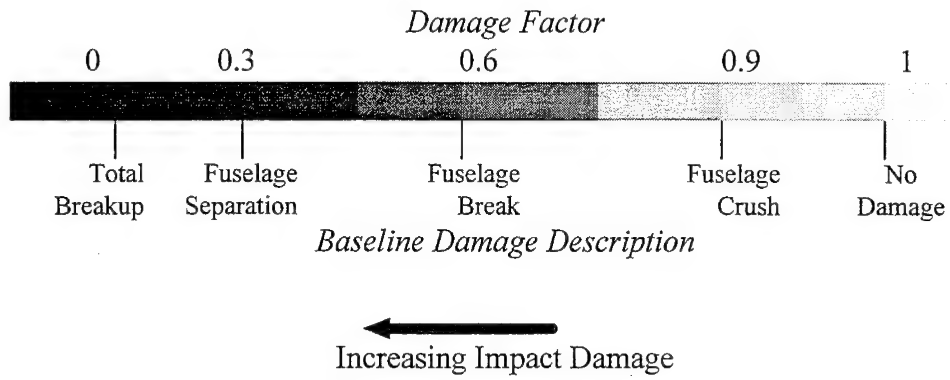


FIGURE 4. DEFINITION OF IMPACT DAMAGE FACTOR

TABLE 4. IMPACT CONDITIONS AND RESULTING DAMAGE IN DITCHING ACCIDENTS

	Date	Aircraft	Speed (Knots)	Pitch Angle	Fuselage Damage
1	05/08/78	B727	138	0.5°	Crushed, compressed, buckled
2	05/02/70	DC-9	90	5.5°	Hull break
3	11/22/69	DC-8	125	5°	Crushed
4	01/13/69	DC-8	155	5°	Separation into three major pieces
5	10/22/63	DC-7C	95	5°	Minimal damage

Although the database is small, some general patterns are evident. Accidents 3, 4, and 5 in table 4 show that for a fixed nose-up pitch angle of 5 degrees, as the impact speed increased from 95 to 155 knots, the level of damage increased from minimal damage to a case where the fuselage separated into three pieces. Accidents 1 and 2 do not fit this pattern, but there may be other factors that came into play at the time of impact. Examples of such factors which are not included in the present model are the sea state and the roll and yaw angles at impact.

The effect of the pitch angle could not be discerned from these five situations, but would be expected to play a major role. Reference 1 indicated that the optimum ditching angle is 10- to 14-degrees nose-up. Table 4 shows that pitching angles as low as 5 degrees can also be favorable. All these mentioned factors were combined to generate the criteria for damage factor prediction for the land accidents as shown in figure 5.

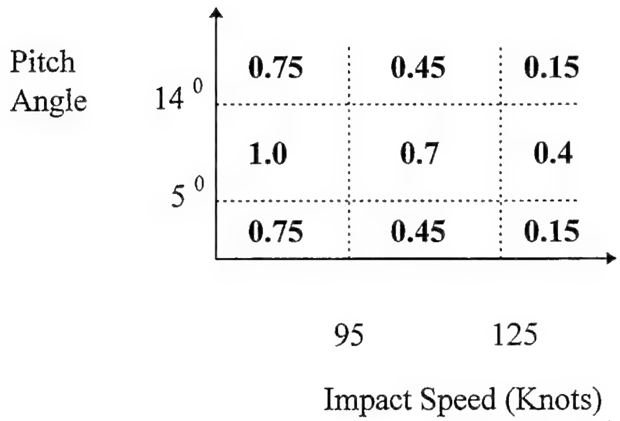


FIGURE 5. ASSESSED DAMAGE FACTOR IN DITCHING ACCIDENTS BASED ON IMPACT SPEED AND PITCH ANGLE

The figure shows that accidents with 5- to 14-degree pitch angle at speeds less than 95 knots are given a damage factor of 1, which implies little or no damage to the main fuselage, and the aircraft is expected to stay afloat for a period equivalent to its substantiated ditching time. As the speed increases the resulting damage factor decreases, implying higher levels of fuselage damage. Furthermore, an even lower damage factor is prescribed if the pitching attitudes are higher than 14 degrees or lower than 5 degrees at impact.

The size and weight of the aircraft at the time of the accident were not considered in determining the damage factor. This was based on an observation in reference 2 where an assessment of the accident data from 153 accidents showed that relative size within jet aircraft has only minor effects on crash performance.

For the overrun scenario, the water accidents from the water accident database (table 1) involving overruns are shown in table 5.

TABLE 5. IMPACT CONDITIONS AND RESULTING DAMAGE IN OVERRUN ACCIDENTS

	Date	Aircraft	Speed at Impact (Knots)	Impact with Obstacles	Impact Damage
1	03/22/92	F-28	Unknown	YES	Fuselage break
2	09/20/89	B737	34	YES	Fuselage break
3	06/27/85	DC-10	Unknown	NO	Fuselage crushed
4	02/20/84	DC-10	Unknown	NO	Fuselage intact
5	01/23/82	DC-10	49	YES	Fuselage break
6	04/07/64	B707	Unknown	NO	Fuselage break

The speed at the time of impact is given if it was indicated in the report. The presence of any significant obstacles that the aircraft could have hit are also noted. These were the two major factors that seemed to determine impact damage and postimpact survivability in accidents involving overruns. Generally, the impact damage seemed to be restricted to fuselage breaks at the most as opposed to ditchings where one case of fuselage separation was observed.

The primary cause of structural damage was from obstacle impact. Typical obstacles were light stanchions, radar equipment, pier structures or even steep gradients, steps, or embankments located at the ends of runways. The effects of the obstacles are difficult to predict since the obstacles can vary substantially in size and type. This can be seen on one extreme in the case of the infamous Potomac River crash where a Boeing 737 collided with a bridge soon after takeoff. The impact was so severe that it resulted in separation of the fuselage into numerous pieces. On the other extreme, accident number four in table 5 involved a collision of the left wing with a wooden pier structure. The damage was restricted to the wing area and caused no direct impact injuries to occupants nor did it cause adverse flooding conditions or otherwise impede evacuation.

The precise effect of the speed at impact was not easy to quantify since the information was available in only two of the six cases. Accident number two, table 5, shows that even low-speed impacts can cause substantial damage if rigid obstacles are encountered. Based on the available data, figure 5 was used to predict the damage factor in land accidents based on the speed of the aircraft as it left the usable portion of the runway and the hypothesized presence of obstacles.

Figure 6 shows that in accidents involving impact speeds less than 40 knots and no obstacles a damage factor of 0.9, equivalent to minor fuselage crush, is expected. At higher speeds, a damage factor of 0.75 is expected. With the presence of obstacles, a damage factor penalty of 0.25 is applied to increase the level of damage expected for all impact speeds.

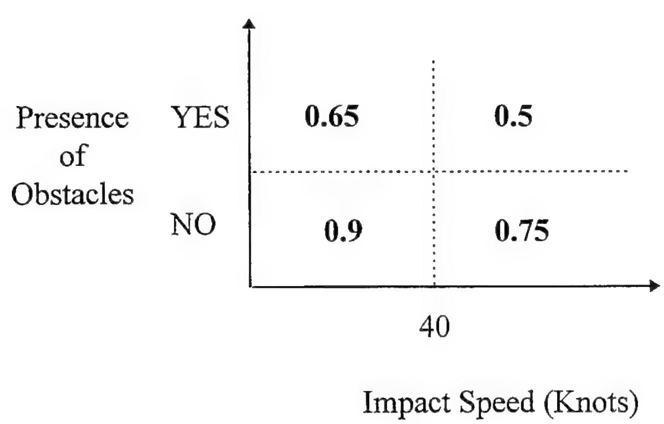


FIGURE 6. ASSESSED DAMAGE FACTOR IN OVERRUN ACCIDENTS BASED ON IMPACT SPEED AND PRESENCE OF OBSTACLES

AIRCRAFT TIME AFLOAT. As per federal regulations, airframe manufacturers are required to demonstrate aircraft flotation times [1]. This is called the ditching substantiation and yields the aircraft's expected time afloat after a planned ditching under favorable conditions. The actual time afloat is a direct function of the buoyancy of the aircraft, which in turn is a function of the weight and volume of the aircraft at the time of the impact. The actual time afloat can be reduced by damage sustained at impact.

An estimate of the aircraft's time afloat was obtained as follows. First a baseline flotation time for a given aircraft in its particular weight configuration at the time of the accident was calculated. The baseline flotation time was reduced by a factor proportional to the damage factor assigned in the previous section.

The case of the DC-7C ditching in Sitka Sound, Alaska (Case 11, table 1), was used as a reference point to establish baseline flotation times. This was the only case where complete flotation data were available. It was stated in the accident report that the aircraft sustained minimal damage and stayed afloat for 24 minutes. The baseline flotation times for all the other aircraft in the land accidents were found by equating the density (weight per unit volume) ratios of the aircraft to the inverse of the flotation times (see appendix A for the equations). The actual weight of the aircraft at the time of the accident was used to calculate the density.

The actual time afloat for the land accident was then further reduced by a factor equal to the damage factor divided by 4; for example, for a baseline flotation time of 30 minutes and a damage factor of 0.4, the aircraft would be expected to remain afloat for 3 minutes (30 x 0.4/4). The reduction factor of 4 was based on the only data point available to establish the effect of fuselage damage on flotation time. This was the case of the DC-9 (case 7, table 1) where the aircraft floated for only 5 to 6 minutes of its substantiated ditching time of 30 minutes after sustaining fuselage breaks at impact. Hence, it was afloat for 16 percent of nominal flotation time, which is a factor roughly equal to the damage factor of 0.6 for fuselage breaks (see figure 3) divided by 4.

For the accidents hypothesized as overruns, the time afloat is calculated similarly. In overrun accidents, it is assumed that the aircraft typically ends up in shallow waters, and the threat of the entire fuselage sinking is almost nonexistent. However, flooding can still occur as the holes in the fuselage can allow water to rush in, thus affecting survivability. This was seen in the case of the Fokker F-28 crash (case 1, table 1) where at least eight people drowned in shallow waters due to evacuation hampered by cabin flooding. Therefore, the calculated time afloat in the case of overruns was treated as a time to evacuate and was used to limit the time available for egress from the aircraft.

EVACUATION TIME. From a review of water impact accidents, it was observed that the following factors primarily affect the evacuation rate:

- level of occupant injury,
- number of available exits,
- level of light in the cabin,
- time available for preparation prior to impact,
- level of cabin debris and damage, and
- effectiveness of the crew.

All of these factors were incorporated in the model by assigning a multiplicative factor that would effectively increase the time required to evacuate the aircraft under these negative conditions. The factors were applied to a so-called baseline evacuation rate, which is a nominal evacuation rate based on the occupants evacuating the aircraft from all available exits in 90 seconds. The details of the calculation and the adjustment factors used in accounting for these circumstances are shown in appendix A.

The number of successful evacuees is then calculated. First the number of occupants that survive impact was estimated. This was based purely on statistical averaging of the number of fatalities and the number of injuries seen in the 11 water impact accidents in table 1. The number of occupants evacuating the aircraft are those that survive impact. An evacuation time is then computed for this number of occupants. If the evacuation time required is less than the time afloat, it is assumed that all the surviving occupants are able to evacuate before the aircraft sinks. Otherwise, the number of occupants proportional to the ratio of the time afloat to the evacuation time required are assumed to successfully evacuate. The remainder are assumed to be entrapped and become fatalities, such as in the Overseas National Airlines ditching (case 7, table 1) where 23 of the 63 occupants drowned as a result of being trapped in sinking sections of the fuselage.

<u>POSTIMPACT SURVIVABILITY</u>. The previous sections described how (based on aircraft damage, flotation time, and required evacuation time) the number of impact survivors who successfully evacuated the aircraft was calculated. In this section the postevacuation survivability of the evacuees is determined by considering the following parameters:

- availability and reliability of rafts,
- reliability of PFDs,
- level of impact injuries,
- level of preparation,
- effectiveness of the crew,
- prevailing weather conditions,
- availability of rescue services,
- depth of the water, and
- temperature of the water.

The first step was to calculate the number of evacuees that used rafts successfully. This in turn depends on the availability of the rafts. Based on section 3 of this study, only flights classified as extended overwater operations (EOO) or those that involved wide-body aircraft were assumed to carry rafts. This is consistent with current federal regulations which require that only flights

operating in EOO carry rafts. In addition, it was observed in section 3 of this study that most wide-body jets also carry rafts in the form of slide-raft combinations, regardless of their operations status.

The other factors mentioned were used as multiplicative factors to improve survivability for positive conditions like mild water temperature and availability of prompt SAR. Conversely, they were used negatively to decrease survivability in situations where a high level of impact injuries and poor weather conditions existed. Details of the calculation are outlined in appendix A.

ANALYSIS RESULTS.

Using the mathematical model described previously, key results were computed for each of the land accidents to determine the hypothetical results if the accident had involved water. The results of these computations are discussed and are organized according to impact survival, evacuation, and postimpact survival. Also presented is a discussion of the hypothetical water impact results relative to the land accidents on which the analyses were based. The results are independently presented for the two major types of water impact scenarios: ditchings and overruns.

IMPACT SURVIVAL. Aircraft damage results are summarized in table 6 and are presented according to the accident scenario. The ditching impacts, which represent more severe impact conditions, generally resulted in more severe damage (fuselage breaks and separations) than the overrun cases. These results are typical of what was observed in the water-related accident cases reviewed for comparison.

TABLE 6. DISTRIBUTION OF AIRCRAFT IMPACT DAMAGE BY ACCIDENT SCENARIO

Accident Category	Aircraft Damage (Number/Percent)				Total
	None	Crush	Break	Separation	
Ditching	0/0	3/25	2/17	7/58	12
Overruns	0/0	5/63	3/37	0/0	8

Table 7 presents the distribution of impact injury severity by accident scenario. The relative distribution of impact injury severity was fixed for both scenarios and was based on the reference group of water-related accidents. This assumption was discussed previously. The table serves to present the numbers of occupants that were predicted to receive overall injury levels of fatal, serious, minor, and none. These numbers were used to calculate the number of occupants that were able to successfully egress and survive in the postimpact water environment.

TABLE 7. DISTRIBUTION OF OCCUPANT INJURY DUE TO IMPACT BY ACCIDENT SCENARIO

Accident Category	Occupant Injuries (Number/Percent)				Total
	Fatal	Serious	Minor	None	
Ditching	29/2	103/7	192/13	1150/78	1474
Overruns	20/2	70/7	129/13	776/78	995

EVACUATION. The time the aircraft stayed afloat was directly influenced by the amount of impact damage sustained by the aircraft. Table 8 contains the distribution of time afloat by impact scenario. In the ditching scenario, seven of twelve aircraft sink in less than five minutes, while seven of eight aircraft in overruns accidents stayed afloat for five minutes or more. As mentioned in the analysis section, the time afloat is merely meant to imply the time available for evacuation in overrun accidents. The entire fuselage is seldom submerged in such cases, but the threat of rising water in the cabin still exits. For the land accidents, the table indicates that in the majority of the cases (7 of 8), between 5 to 10 minutes were available for evacuation.

Very little data are available on the actual time the aircraft stayed afloat in the five actual ditching accidents. The only known flotation times were 24 minutes for the DC-7C (case 11, table 1), and 5-6 minutes for the DC-9 (case 7, table 1). It was observed that these flotation times were in strong proportion to the level of damage, and a similar effect was incorporated into the model. The aircraft that sustained more impact damage were determined to be less able to maintain buoyancy.

TABLE 8. DISTRIBUTION OF AIRCRAFT TIME AFLOAT BY ACCIDENT SCENARIO

Accident Category	Time Afloat (minutes)					Total
	<1.5	1.5-3	3-5	5-10	>10	
Ditching	0	2	5	5	0	12
Overruns	0	0	1	7	0	8

One of the main purposes of determining the impact damage, impact injury severity, and time afloat was to determine the relative success of evacuation from the aircraft for each accident. A critical parameter was the calculated time required to evacuate for a given aircraft type, passenger load, and damage condition (including number of usable exits). Table 9 presents the distribution of evacuation results by accident scenario.

In ditching accidents, 18 percent of the occupants were unable to evacuate the aircraft before it submerged (82 percent were successful). In contrast, only 2 percent of occupants were trapped in the overrun accidents (98 percent were successful). This difference can be attributed to the time differential between the time the aircraft remained afloat (or the time available for evacuation) and the time required for successful evacuation of all occupants. Note that for the ditching

accidents, there is relatively little difference between the average time that the aircraft remained afloat and the average time required for all occupants to successfully evacuate. The difference between these two average times for overrun accidents is approximately three minutes. These time results, when considered with the number of successful evacuees, indicate that on average there was significantly more time for successful evacuation in slide/roll accidents than there was in high-energy impact accidents. This trend is consistent with that observed in actual water-related accidents.

TABLE 9. DISTRIBUTION OF EVACUATION RESULTS BY ACCIDENT SCENARIO

Accident Category	Average Time Afloat (minutes)	Average Required Evacuation Time (minutes)	Total Post-Impact Survivors	Successful Evacuees	Entrapped Occupants	Escape Rate (percent)
Ditching	4.84	4.35	1444	1179	265	82
Overruns	6.80	3.78	975	956	19	98

POSTIMPACT SURVIVAL. The postimpact survival of the occupants in this analysis depended on a large extent on the use and effectiveness of flotation equipment. Two main types of equipment were assumed to be available to the occupants, rafts and personal flotation devices (PFDs). The usage of these two types of equipment is presented in table 10 for both impact scenarios. For this analysis it was assumed that occupants that were not able to get into rafts relied solely on PFDs for flotation. The expected reliability or effectiveness of rafts and PFDs is also taken into account in the model.

As mentioned earlier, the benefit of rafts is only available to survivors in EOOs or in wide-body jets (where slide/raft combinations are available). Of the land accidents analyzed, 25 percent of both ditching and overrun accidents were of aircraft equipped with rafts. It can be seen in table 10 that roughly the same proportion of survivors were able to use the available rafts, and the remainder were forced to be in water contact, protected only by PFDs.

TABLE 10. DISTRIBUTION OF FLOTATION USAGE BY ACCIDENT SCENARIO

Accident Category	Extended Overwater Operations (Percent)	Flotation Equipment Used (Number/Percent of Total)		Total Evacuees
		Rafts	PFDs	
Ditching	25%	332/28	847/72	1179
Overrun	25%	322/34	634/66	956

The drowning and cold-water exposure fatalities that occurred relative to the EOO status of a particular flight is given in table 11.

TABLE 11. DISTRIBUTION OF IMPACT DROWNING AND EXPOSURE FATALITIES AS A FUNCTION OF RAFT AVAILABILITY (EOO STATUS)

Accident Category	Drowning and Exposure Total Fatalities/Percent of Total		Total Evacuees
	EOO	Non EOO	
Ditching	45/3.8	310/26.3	1179
Overrun	21/2.2	41/4.3	956

It can bee seen from table 11 that availability of rafts in ditching accidents caused an almost seven fold decrease in postimpact fatalities. In overruns, rafts had a reduced life saving effect, but still the number of fatalities were cut in half.

Once the use of flotation equipment was determined, the number of postimpact injuries (drowning and exposure) were computed. Table 12 contains the distribution of drownings and exposure fatalities for the two accident scenarios. In ditching accidents, a total of 30.1 percent of the successful evacuees became fatalities, mainly from drowning (29.3 percent). Only 6.5 percent of the successful evacuees in overruns became fatalities, again largely from drowning. This discrepancy in postimpact fatalities between the two accident scenarios can be attributed in part to the greater availability of rescue personnel and the reduced depth of water as is generally the case in overruns as discussed in the analysis section.

TABLE 12. DISTRIBUTION OF POSTIMPACT INJURY BY ACCIDENT SCENARIO

Accident Category	Successful Evacuees	Occupant Fatalities (Number/Percent of Total)		
		Drownings	Exposure	Total
Ditching	1179	346/29.3	9/0.8	355/30.1
Overrun	956	57/6.0	5/0.5	62/6.5

<u>SUMMARY OF HYPOTHETICAL WATER IMPACT FATALITIES</u>. Having discussed the three main phases of the analysis: impact, evacuation, and postimpact, the cause and relative number of fatalities from all three phases may now be compared. Table 13 summarizes the water accident fatality results from the hypothetical analysis for both accident scenarios. The fatality rate for ditching accidents is 44 percent while that for overrun accidents is only 10.1 percent. As would be expected, the more severe scenario results in a higher fatality rate. Another significant result is that for both scenarios, the majority of deaths were caused by drowning, with a much higher rate being calculated for the ditching accidents.

TABLE 13. SUMMARY OF WATER ACCIDENT FATALITIES BY ACCIDENT SCENARIO

Accident Category	Occupant Fatalities (Number/Percent of Total)					Total Onboard
	Impact	Drowning/ Entrapment	Drowning/ Postimpact	Exposure	Total Fatalities	
Ditching	29/2	265/18	346/23.4	9/0.6	640/43	1474
Overruns	20/2	19/1.9	57/5.7	5/0.5	101/10.1	995

LAND ACCIDENTS VERSUS HYPOTHETICAL WATER ACCIDENTS. A comparison can be made of the impact damage to the aircraft as a result of the actual ground impact versus that from the hypothesized water impact. This is done in table 14. In both scenarios, the level of impact damage to the aircraft was found to be very similar. The impact damage in case of the land accidents studied may be biased to a higher level due to the inclusion of two nonsurvivable accidents among the 20 cases considered.

TABLE 14. DISTRIBUTION OF AIRCRAFT IMPACT DAMAGE—LAND AND WATER ACCIDENTS

Accident Category	Land Accidents				Hypothetical Water Accidents			
	None	Crush	Breaks	Separation	None	Crush	Breaks	Separation
Ditching	0	2	2	8	0	2	3	7
Overrun	0	5	2	1	0	5	3	0

It is interesting to compare the fatality rate between the actual land accidents and the hypothesized water accidents. The results are shown in table 15. A distinction is made between the impact fatalities and the postimpact fatalities. This is a crucial distinction since it was mentioned earlier that the postimpact environment in land and water accidents is very different. The major postcrash hazard in land accidents is the presence of postcrash fires and resulting deaths due to asphyxia, smoke inhalation, and thermal injuries. In contrast, survivors in water accidents are faced with the threat of a drowning in a sinking fuselage, dependence on flotation devices, and the additional hazards of exposure and drowning after evacuation.

TABLE 15. DISTRIBUTION OF OCCUPANT INJURY—LAND AND WATER ACCIDENTS

Accident Category	Land Accidents Fatalities/Percent of Total		Hypothetical Water Accidents Fatalities/Percent of Total		Total Occupants Onboard
	Impact	Postimpact	Impact	Postimpact	
Ditching	501/34	150/10.2	294/20	355/24	1474
Overrun	0/0	2/0	39/3.9	62/6.2	995

It can be seen that the number of impact fatalities is much higher in the land accidents. This can be attributed to the inclusion of two nonsurvivable accidents among them, where 184 fatalities were caused instantaneously at impact. If these were not counted, then for the ditching scenario the number of impact fatalities is around 20 percent for both land and water impacts. This seems reasonable when considering that the level of impact damage was similar in table 14. Postimpact fatalities however were almost two and a half times higher in water accidents than in the land accidents. The percentage of both impact and postimpact fatalities is much higher in overrun accidents. Only 2 of 995 occupants in the actual land accident overruns were fatally injured. Postimpact fatalities were seen to occur in the actual water accidents in the overrun category, and the hypothetical results are in agreement with that trend.

SECTION 2. AIRPORT WATER RESCUE

INTRODUCTION.

Because most transport aircraft accidents occur close to airports during the approach or departure phase of flight [1], airport water rescue programs play a vital role in the survival of victims in transport aircraft water accidents. Therefore, along with the crashworthiness and ditching performance of aircraft and the performance of flotation equipment, the capability of airport water rescue programs must be considered to fully evaluate the survival environment.

In the United States, at least 179 fully certified airports are within five miles of a significant body of water [1]. A survey of worldwide airports found that of the 156 airports in the U.S., 120 (77 percent) had at least one over-water approach. The survey also found that 75 percent of all worldwide airports are located close to a significant body of water and have one or more over-water approaches.

Because of increasing air traffic, and the resulting need for more airport space, coupled with increasing urban encroachment of airport property, airports may be pushed over the edge into a water environment. This is demonstrated in the case of the new Kansai airport in Osaka, Japan, where the airport was built as an independent island in the Osaka Bay. At Macau International Airport in South China, the taxiways lead to a single large runway constructed on landfill surrounded by water on all sides.

In the present study, a survey was conducted to evaluate the airport water rescue plans at airports serving transport category aircraft. This report outlines the results of the survey. The main features of the survey include:

- Airport Selection. Airports for the study were selected to study water rescue programs at airports of different sizes, in different climatic regions, and in proximity to different types of water bodies.

- Survey Scope. The areas of airport water rescue, equipment, facilities, personnel, and the characteristics of the general airport water environment were studied.

BACKGROUND.

Current regulations were reviewed to identify the requirements for organizing and operating airport water rescue plans. Advisory Circular (AC) 150-5210-13A [7] directly addresses airport water rescue plans and is also summarized here to outline issues in airport water rescue. The regulatory review also helps contrast current regulations with recommendations issued in the past by the NTSB.

FEDERAL REGULATIONS AND ADVISORY CIRCULARS. Airport rescue and firefighting operations are addressed in FAR Title 14, Part 139, entitled "Certification and Operations: Land

Airports Serving Certain Air Carriers." The regulations provide rules to determine the aircraft rescue and firefighting (ARFF) index for a given airport. The index for an airport can range from A to E depending on the size of the aircraft and the frequency of daily departures within a given size range of aircraft using the airport. Table 16 shows how the index is determined.

TABLE 16. ARFF INDEX DETERMINATION AS PER FEDERAL AVIATION REGULATION PART 139.315

Aircraft Length Range (in feet)	Frequency of Daily Departures	ARFF Index
<90	≥1	A
≥90, <126 ≥126, <159	≥5 <5	B
≥126, <159 ≥159, <200	≥5 <5	C
≥159, <200 ≥200	≥5 <5	D
≥200	≥5	E

The index is used as a guide to regulate the minimum number of firefighting vehicles, quantity of fire-extinguishing agent, and discharging capacity required at airports. In this report, the index is used as a measure of the size of the airport rescue facilities currently in use at an airport.

FAR Title 14, Part 139.319 entitled "Aircraft Rescue and Firefighting: Operational Requirements" outlines the operational requirements for airport rescue and firefighting vehicles. Vehicle response requirements are given in terms of the minimum time required for at least one response vehicle to reach the mid point of the farthest runway. No response times are given for deploying vehicles into a body of water neighboring the airport, if applicable. This paragraph also defines the required areas of personnel training. These include airport and aircraft familiarization, safety, communications, use of equipment and extinguishing agents, and aircraft evacuation and firefighting. No specific training is required for water rescue.

FAR Title 14, Part 139.325 entitled "Airport Emergency Plan (AEP)" calls for the airports to develop and maintain a detailed emergency plan. The plan is required to have instructions for response to a variety of emergencies including water rescue situations. The plan should also contain

> "provisions, to the extent practicable, for the rescue of aircraft accident victims from significant bodies of water or marsh lands adjacent to the airport which are crossed by approach and departure flight paths of air carriers. A body of water or marsh land is significant if the area exceeds one quarter square mile and cannot be traversed by conventional land rescue vehicles. To the extent practicable, the plan should provide for rescue vehicles with a combined capacity for handling the

maximum number of persons that can be carried onboard the largest air carrier aircraft that the airport reasonably can be expected to serve."

The ACs relevant to airport rescue departments facilities, operations, and equipment are in the 150 Series. Those that apply to the current study are listed in appendix B. Reference 7 provides guidance to airport operators in preparing for water rescue operations and is discussed in detail in the next section.

AIRPORT WATER RESCUE PLANS, FACILITIES, AND EQUIPMENT (AC 150/5210-13A). AC 150/5210-13A provides guidance in preparing for water rescue operations in the vicinity of an airport. Some of the topics covered by this AC are presented in this section.

Water Survival. Survival in the water is affected by the presence of postimpact fires, fuel/vapor ingestion, hypothermia, injury from debris, drowning, freezing, or attack from marine life. The water temperature is a determining factor of the amount of time a person can survive before the onset of hypothermia which could lead to death. Exposure to the elements can be minimized by rescue vehicles equipped with the appropriate warming equipment available from rescue through transit to a medical facility.

Water Rescue Responsibilities and Planning. Certified airports are required to have provisions for water rescue. This can be done by the airport itself serving as a primary response agency in cooperation with other local public safety organizations such as the U.S. Coast Guard or the Harbor Patrol. Alternatively, airports may officially designate some other rescue agency for primary response to water rescue situations by signing mutual aid agreements. These mutual aid agreements are part of the airport plan. In planning, the airport's role as a supporting agency should be clearly identified. A support inventory stating the available services, equipment, and capabilities should be maintained and regularly updated. The primary response agency should establish procedures for the rescue and transport to safety and triage facilities onshore. The airport plan should also address other factors such as notification regarding the accident response times, security traffic control, training, and drills.

Personnel and Training. Personnel for water rescue are generally selected from the trained ARFF or airport police personnel. Training must prepare personnel for seamanship and small boat handling skills; SAR planning, techniques, and procedures; marine rescue; and scuba diving.

Communications. Reliable voice and electronic communications with the primary response agency or between airport and mutual aid agencies is crucial. The emergency plan should address the establishment of a command post to direct the rescue effort. This may require the airport to purchase marine radios or install marine channels on their radios.

Rescue Vehicles and Equipment. Vehicles must be suitable for the requirements of the particular water body as well as other special conditions such as the presence of ice, wave height, water temperature, etc. For example, airports next to marshlands or swamps may utilize shallow draft boats, airboats, or amphibious vehicles. Vehicles that can be used to facilitate water rescue

can be divided into several categories depending on their size and the primary function that they can be expected to perform. Appendix C shows the classification and a brief description of each. Appendix D lists some of the auxiliary equipment that may be useful in a water rescue.

NATIONAL TRANSPORTATION SAFETY BOARD RECOMMENDATIONS. The phase-I report [1] identified several accidents that involved the aircraft ending up in a body of water close to an airport. Some of the accident reports included NTSB recommendations to the FAA pertaining to water rescue operations. NTSB recommendations from two separate safety studies conducted by the board [3, 8] are also presented.

- Recommendation A82-89. The NTSB recommended that airport plans must be prepared to deal with situations in the most extreme weather conditions expected in the region. This recommendation arose from the Air Florida accident at Washington National Airport where most of the available equipment was rendered useless due to extremely cold weather and icy conditions on the Potomac River.

- Recommendation A82-88. NTSB recommended the FAA evaluate the adequacy of water rescue plans, facilities, and equipment at airports with approach and departure paths over water. This resulted from the NTSB determination that the airport did not provide adequate resources to transport survivors from the accident site to a safe and comfortable location, based on an investigation of the World Airways accident at Boston-Logan [9].

- Recommendation A82-87. The NTSB issued this recommendation in response to the Air Florida accident in 1982 at Washington National Airport. It recommended that the FAA provide for essential equipment and increased personnel training to improve the water rescue capabilities at Washington National Airport in all anticipated weather conditions and provide necessary funding for surrounding communities and jurisdictions which would be called on to support the airport's rescue response.

- Recommendation A84-32. The NTSB recommended that the FAA revise 14 CFR 139.49 to require a minimum of two firefighters per vehicle and to specifically define minimum standards for training of crash fire rescue personnel [8].

- Recommendation A84-34. The NTSB recommended that the FAA revise 14 CFR 139.55 to require full-scale demonstration of certified Airport Emergency Plans (AEPs) and procedures at least once every two years and to require an annual validation of notification arrangements and coordination agreements with participating parties. [8]

The NTSB safety study examining air carrier overwater emergency equipment and procedures pointed out that an FAA staff study addressed the need to define a perimeter around an airport within which the presence of significant bodies of water will require the development of a water rescue plan. Furthermore, the FAA staff study recommended regulations requiring airports to conduct semiannual evaluations of water rescue capability, including staging of a simulated disaster to evaluate typical winter and summer (water rescue) conditions [3].

As a result of the World Airways accident at Boston-Logan, the NTSB's report commented on the use of mutual aid agencies [3]. As observed later in this current report, some airports in proximity to water rely either solely, or to a very large extent on mutual aid agencies, typically the U.S. Coast Guard or local Harbor Patrol. The NTSB recognized that while these mutual aid agencies can be expected to respond to airport emergencies, they will not be dedicated to this function. They will typically have broader SAR responsibilities and will generally not be close at hand. It should be recognized that these units cannot reach the waters adjacent to the airport to provide immediate response to persons immersed in the water.

AIRPORT SURVEY.

The status of water rescue capabilities at several airports around the country were surveyed. The candidate airports were in three size categories and were selected to represent a variety of different climates as well as a range of water environments. At each of the selected airports, the survey addressed water rescue vessels, equipment, facilities, personnel, training, distance from water, water depth, and other features of the water environment and response times. The data were collected from interviews conducted with ARFF personnel, fire chiefs, water rescue coordinators, and operations managers at airports. Additional data were obtained from water rescue instructors and in some cases from manufacturers of water rescue vehicles and equipment.

SELECTION CRITERIA. Twenty-three airports in three size categories were selected. The airports were chosen from a database of 60 airports. The 60 airports were selected from the phase-I airport database based on the following criteria: located in the 50 contiguous states plus Hawaii and Alaska, located within 5 miles of a significant body of water, and have at least one overwater approach.

The database of 60 airports was further reduced to obtain a sample that included a good mix of the following:

- Large-, medium-, and small-hub airport classifications were based on the number of operations. Airports with yearly operations in excess of 350,000 were classified as large, those with less than 350,000 but greater than 175,000 were classified as medium, and those with less than 175,000 were considered as small airports. Eight large, seven medium, and eight small airports were identified for the survey.

- Airports in different geographical locations were selected to represent varying weather patterns. For this purpose the country was subdivided into five regions: North Atlantic, South Atlantic, Central, North Pacific (including Alaska), and South Pacific (including Hawaii).

- Airports were located adjacent to different types of water bodies. The type of water body plays a significant role in determining the type of vessels, equipment, and training the rescue plan embodies. For simplicity, the categories in this subdivision were ocean, lake, bay, and river.

Figure 7 is a map subdivided to show the geographical categories and the selected airports within each category. Airport size is also indicated. Table 17 lists the selected airports with the airport's name, location, and designation within each size category. The ARFF index, the number of operations per year, and the predominant body of water is also listed. The airport is further characterized as type W or type N as discussed in the next section. Some airports may have more than one distinct body of water in its vicinity.

AIRPORT CATEGORIES: TYPE W AND TYPE N. It was observed from the study that there exists a tremendous amount of variation in water rescue operations at the airports surveyed. The difference arises primarily from the degree of dependence on mutual aid from other public safety agencies. This dependence ranged from complete to minimal, depending on several factors that are discussed later. This was found to be a distinctive factor in studying airports, therefore the survey airports are presented in two different categories:

- Type W: Airports with at least some on-site water rescue equipment or facilities and ARFF personnel trained to handle water rescue situations with cooperative reliance on mutual aid. This category includes airports with extensive water rescue operations in place.

- Type N: Airports with little or no on-airport water rescue equipment or facilities, ARFF personnel with little or no formal training for water rescue situations, and total reliance on mutual aid.

Table 18 lists the selected airports and their water rescue category (W or N). The table also shows whether the airport is located immediately adjacent to the body of water under consideration or whether it was some distance away from it.

Table 19 summarizes the airport characteristics and the breakdown of type W and N airports in relation to their size, their ARFF index, and their adjacency to the water. The table indicates that 75 percent (6 of 8) of large airports, 43 percent (3 of 7) of medium airports, and 25 percent (2 of 8) of small airports were type W. This trend indicates that other factors aside, the larger the airport, the greater the likelihood that it contains water rescue facilities and equipment on-site. In relation to the ARFF index, 66 percent of index E, 50 percent of index D, 37 percent of index C, and none of the index B airports were type W airports. With regards to adjacency, 65 percent (9 of 14) of airports where the body of water borders the airport were found to be type W airports. In comparison, only 22 percent (2 of 9) of the airports where the body of water lay within 5 miles of the airport (but not directly adjacent to airport property) were type W airports.

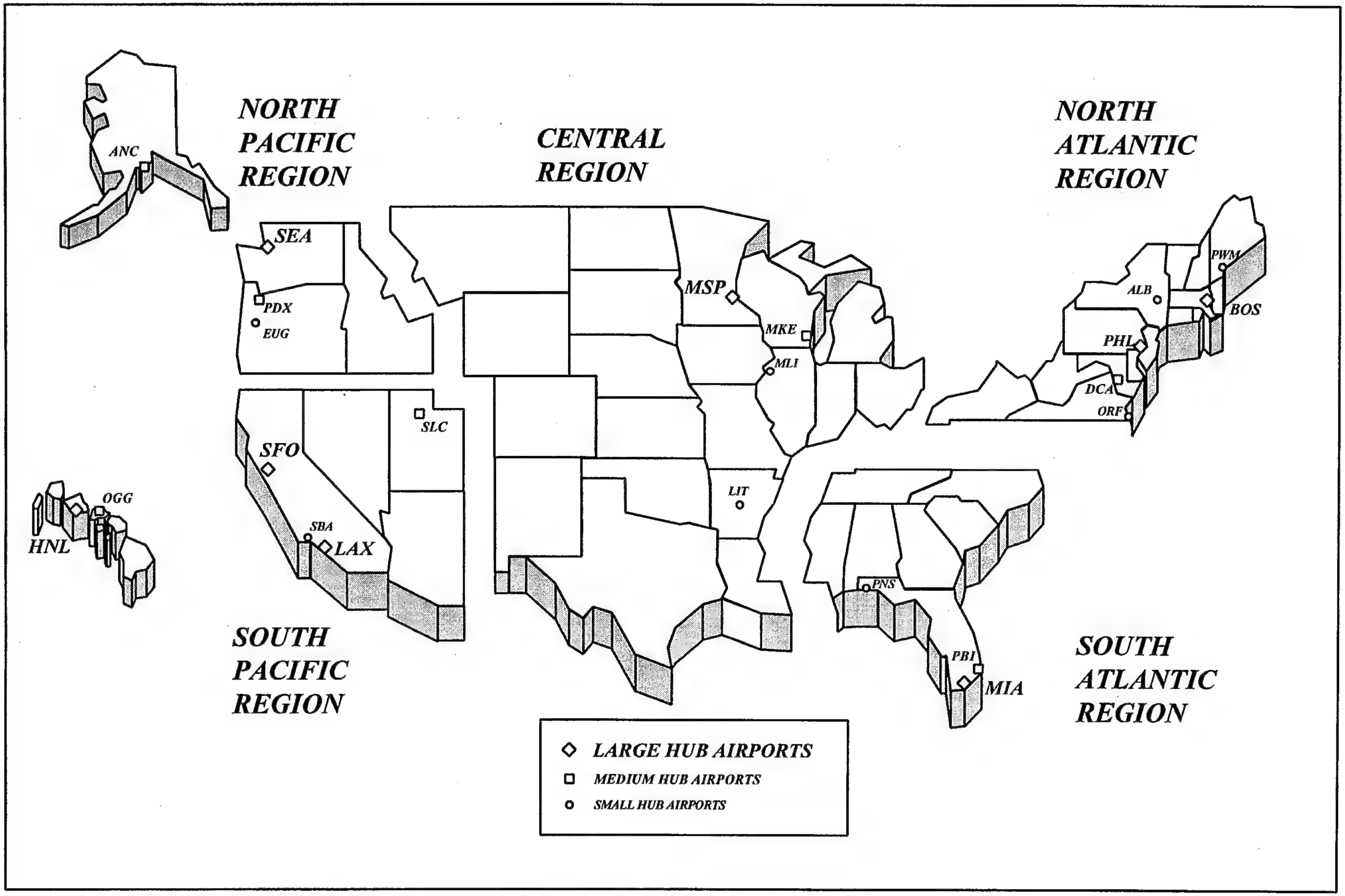


FIGURE 7. SURVEYED AIRPORTS CATEGORIZED BY SIZE AND REGION

TABLE 17. SELECTED AIRPORTS: ID, SIZE, LOCATION, OPERATIONS, ARFF INDEX, WATER ENVIRONMENT

	No.	Airport Name	ID	Location	Operations	ARFF Index	Water Environment
	1	Los Angeles International	LAX	Los Angeles, CA	681,845	E	Pacific Ocean
L	2	Miami International	MIA	Miami, FL	527,545	E	Blue Lagoon, Biscayne Bay
A	3	Boston-Logan International	BOS	Boston, MA	495,347	E	Boston Harbor/Atlantic Ocean
R	4	Minneapolis/St. Paul International	MSP	Minneapolis, MN	442,341	E	Mother Lake, Minnesota River
G	5	San Francisco International	SFO	San Francisco, CA	423,404	E	San Francisco Bay
E	6	Philadelphia International	PHL	Philadelphia, PA	390,736	D	Delaware and Schuykill Rivers
	7	Honolulu International	HNL	Honolulu, HI (Oahu)	365,195	E	Keehi Lagoon/Pacific Ocean
	8	Seattle-Tacoma International	SEA	Seattle, WA	339,968	E	Puget Sound, Elliot Bay
M	1	Salt Lake City International	SLC	Salt Lake City, UT	324,595	D	Great Salt Lake
E	2	Washington National	DCA	Washington, D.C.	315,912	C	Potomac River
D	3	Portland International	PDX	Portland, OR	280,263	E	Columbia River
I	4	Palm Beach International	PBI	W. Palm Beach, FL	230,903	D	Cloud Lake, Palm Beach Inlet
U	5	Anchorage International	ANC	Anchorage, AK	218,279	E	Cook Inlet
M	6	General Mitchell International	MKE	Milwaukee, WI	198,529	C	Lake Michigan
	7	Kahului Airport	OGG	Kahului, HI (Maui)	173,002	D	Pacific Ocean
	1	Little Rock National Airport	LIT	Little Rock, AR	171,399	C	Arkansas River
S	2	Albany County Airport	ALB	Albany, NY	160,587	C	Mohawk River
M A	3	Norfolk International	ORF	Norfolk, VA	134,564	C	Little Creek/Chesapeake Bay, Elizabeth River
L	4	Portland International Jetport	PWM	Portland, ME	126,353	C	Fore River/Casco Bay
L	5	Santa Barbara Municipal	SBA	Santa Barbara, CA	10,000	C	Channels, East and West of Airport
	6	Pensacola Regional	PNS	Pensacola, FL	8,765	C	Gulf of Mexico
	7	Mahlon Sweet Field	EUG	Eugene, OR	8,074	B	Fern Ridge Reservoir
	8	Quad City Airport	MLI	Moline, IL	6,286	B	Rock River

TABLE 18. AIRPORT TYPE AND WATER ADJACENCY

	No.	ID	Type	Adjacent	Non-adjacent	Water Environment
	1	LAX	N	x		Pacific Ocean
L	2	MIA	W	x		Blue Lagoon, Biscayne Bay
A	3	BOS	W	x		Boston Harbor/Atlantic Ocean
R	4	MSP	W		x	Mother Lake, Minnesota River
G	5	SFO	W	x		San Francisco Bay
E	6	PHL	W	x		Delaware and Schuylkill Rivers
	7	HNL	W	x		Keehi Lagoon/Pacific Ocean
	8	SEA	N		x	Puget Sound, Elliot Bay
M	1	SLC	N		x	Great Salt Lake
E	2	DCA	W	x		Potomac River
D	3	PDX	W	x		Columbia River
I	4	PBI	W		x	Cloud Lake, Palm Beach Inlet
U	5	ANC	N	x		Cook Inlet
M	6	MKE	N		x	Lake Michigan
	7	OGG	N	x		Pacific Ocean
	1	LIT	N		x	Arkansas River
S	2	ALB	N		x	Mohawk River
M A	3	ORF	W	x		Little Creek/Chesapeake Bay, Elizabeth River
L	4	PWM	N	x		Fore River/Casco Bay
L	5	SBA	W	x		Channels, East and West of Airport
	6	PNS	N	x		Gulf of Mexico
	7	EUG	N		x	Fern Ridge Reservoir
	8	MLI	N		x	Rock River

TABLE 19. TYPE W AND N TYPE AIRPORTS SUMMARY

	Category	Type W	Type N	Total
Size	Large	6	2	8
	Medium	3	4	7
	Small	2	6	8
	TOTAL	11	12	23
ARFF Index	E	6	3	9
	D	2	2	4
	C	3	5	8
	B	0	2	2
	TOTAL	11	12	23
Water Location	Adjacent	9	5	14
	Nonadjacent	2	7	9
	TOTAL	11	12	23

In summary, the likelihood that a given airport has extensive on-site water rescue plans depends heavily on the size of the airport, its location relative to water, and its ARFF index. It was observed that a large airport located immediately adjacent to a body of water and serving very large aircraft (higher ARFF index) is likely to be type W and have provisions for detailed water rescue operations, facilities equipment, and dedicated personnel.

SURVEY RESULTS.

The equipment, facilities, and personnel that are discussed are only those that are available at the resident water rescue program at the airport. The resources available to the airport may be greatly enhanced due to the mutual aid agreements between various local public safety departments.

TYPE W AIRPORTS. The next few sections describe the 11 type W airports in terms of the general airport water environment, the available water rescue equipment including vessels and accessories, and the water rescue facilities and personnel.

Airport Water Environment. The airport water environment was found to be considerably different from airport to airport. The relevant features of the airport environment at type W airports are presented and evaluated in a series of tabulations described.

Table 20 indicates the significant bodies of water that were adjacent to the airport. The water body type is identified as being either a Lake (L), River (R), Bay (B), or Ocean (O). This is not an exhaustive set of categories; however, they do represent a variety of different conditions such as depth, size, boundary characteristics, and the presence of marine life. The following describes typical features that exemplify the categories.

TABLE 20. TYPE W AIRPORTS: WATER BODY CHARACTERIZATION, DISTANCE, AND ACCESS

	Airport	Water	Type(1)	Shortest Distance	Access (Y/N)(3)
	MIA	Blue Lagoon/Tamiami Canal	L	1,050 ft	Y
		Biscayne Bay/Atlantic Ocean	B/O	5.3 miles	N
L	BOS	Boston Harbor	B/O	Adjacent(2)	Y
A		Chelsea Creek	R	4,650 ft	N
R	MSP	Mother Lake	L	3,000 ft	Y
G		Lake Nokomis	L	6,650 ft	N
E		Minnesota River/Gun Club Lake	R/L	1,650 ft	N
	SFO	San Francisco Bay	B	Adjacent(2)	Y
	PHL	Delaware River	R	Adjacent(2)	Y
	HNL	Keehi Lagoon	B	Adjacent(2)	Y
		Pacific Ocean	O	Adjacent(2)	Y
M	DCA	Potomac River	R	Adjacent(2)	Y
E	PDX	Columbia River	R	Adjacent(2)	Y
D	PBI	Cloud Lake	L	2,300 ft	N
		Palm Beach Inlet/Atlantic Ocean	B/O	2 miles	N
S	ORF	Little Creek, Chesapeake Bay	B/O	0	Y
M		Elizabeth River	R	4.5 miles	N
A	SBA	East Channel	R	200 ft	Y
L		West Channel	R	150 ft	N
L					

1. Symbol — Type
   - O — Ocean
   - R — River
   - B — Bay
   - L — Lake
2. Adjacent: Water is adjacent to end of runway or within 1,000 ft.
3. Access: Presence of road or other means specifically for water rescue effort.

Oceans often have steep increases in depth moving away from shore. Tidal action can be seen, and dangerous marine life may be present. Water rescue in this environment should account for these factors by employing larger, more resilient vessels. Due to the depths involved, rescue divers must form an essential part of the rescue effort. Also included in this water environment category are gulfs and seas.

Rivers in most instances have fast moving water or at least some light to moderate current. In the case of Portland International Airport in Oregon for example, even when ambient temperature conditions are below freezing, the Columbia river never freezes in the vicinity of the airport. The rescue efforts have therefore incorporated operations and equipment for swift water training and rescue. The presence of heavy marine traffic, including both commercial and

recreational users, requires precautionary measures on part of the rescue effort. Also included in this water environment category are inlets, estuaries, and channels.

Bays are unique in that they are typically surrounded by mud flats and low lying waters. This environment makes navigating the water body extremely difficult and is a major problem for many airports, with San Francisco International and Portland Jetport (Maine) as prime examples. Freezing is likely to occur near shore as is seen in the case of Boston Harbor. This condition is addressed by personnel making routine checks of the shoreline at end of the airport runways and, if required, employing means to break the ice and drift it offshore.

Lakes are a relatively benign environment. One main problem is that the calm waters are very susceptible to freezing. Lakes may also have neighboring marshland or low lying water. These conditions also hamper navigation and require special vehicles such as airboats which are discussed later. Lagoons are also included in this water environment category.

Table 20 also shows the shortest distance from the end of a runway at the airport to the nearest body of water. The presence of an access road to the water is also indicated. Access is meant to indicate the presence of a road or path meant specifically to gain access to the water and launch rescue vehicles. The same access is typically provided for other purposes such as maintaining lights and other navigational equipment. Access through commercial streets and highways is not considered adequate. As expected, all bodies of water that lay adjacent to the airport had means of access. Typically in situations where the water is over 1000 ft. away, no direct access means were observed. This was caused by a variety of obstructions between the runway and the shoreline of the body of water as seen in table 21. Table 21 also shows the runways with overwater approaches or departures. It was observed that type W airports in the study had 50 to 100 percent of the runway approaches (or departures) overwater. If the runway is not immediately adjacent to the edge of the water, the table notes the type of terrain found between the end of the runway and the water body. The terrain is categorized as wetlands, mudflats, woods, sand, residential or business areas, open land, and/or highways or public roads. The distance traveled over the approach is the approximate flight distance traveled over the water on a typical instrument approach (or departure). An infinity symbol (∞) indicates the distance traveled overwater during approach is over 10,000 ft. In general the distance traveled varies depending on the approach path.

Table 22 indicates the extreme temperatures likely to be encountered for all the bodies of water surrounding the airport. It is important to note that these are approximate temperatures. The actual temperature is a strong function of depth, currents, and surface weather conditions. The maximum possible water depth is also indicated in feet. The depth is a typical value depending on the nature of the water body. For example, the depth given for oceans is the maximum depth expected over a typical approach, roughly between 0 to 2 miles offshore. Airports close to deep waters should provide for certified divers and have deep-water SAR equipment. The table also identifies special conditions relevant to proper water rescue planning

TABLE 21. RUNWAYS WITH OVERWATER APPROACH/DEPARTURE PATHS AND UNDERLYING AREA DESCRIPTIONS

	Airport	Runways Total	% App/Dep Overwater	Runways with Over-water App/Dep	Water	Dist. Over-water	Intermediate Area								
							WET	MUD	WOO	SAN	RES	BUS	OPN	SD	HWY
LARGE	MIA	3	67%	27L,27R,30	Biscayne Bay/Atlantic Ocean	∞				x	x	x			x
				9R	Blue Lagoon/Tamiami Canal	900 ft									
	BOS	4	75%	33L,22L,22R,4L,4L	Boston Harbor	∞									
				15R	Chelsea Creek	660 ft					x	x			x
	MSP	3	67%	11R	Mother Lake	660 ft	x		x						
				11L	Lake Nokomis	2,000 ft			x		x	x			x
				29L,29R	Minnesota River/Gun Club Lake	3,300 ft	x		x						x
	SFO	4	50%	19L,19R,28L,28R	San Francisco Bay	∞		x							
	PHL	3	84%	27L,27R	Delaware River	∞						x			
				9R, 9L	Delaware River	∞						x			
				35	Delaware River	∞					x	x			
	HNL	4	100%	26R,22L,22R	Keehi Lagoon	∞				x					
				26L,4L,4R,8R,8L	Pacific Ocean	∞				x					
MED	DCA	3	100%	3,21,33,15,36,18	Potomac River	∞					x	x			x
	PDX	3	100%	28L,28R	Columbia River	∞				x			x		
				10L,10R	Columbia River	∞				x			x		
				20	Columbia River	4,000 ft					x	x			x
	PBI	2	50%	27R	Cloud Lake	1,000 ft							x		x
				31	Atlantic Ocean	∞				x	x	x	x		x
SMALL	ORF	2	50%	5	Elizabeth River	∞					x	x			x
				23	Little Creek, Chesapeake Bay	∞					x	x			x
	SBA	1	100%	25	East Channel	75 ft								x	
				7	West Channel	150 ft								x	

WET = Wetlands; MUD = Mudflats; WOO = Woods; SAN = Sand; RES = Residential; BUS = Business; OPN = Open; SD = Sharp Drop;
HWY = Municipal Roads
∞ = Distance greater than 1 mile (5,280 ft.)

Note: Only Part 121, 135 runways are included in analysis. General aviation runways are not considered.

TABLE 22. WATER BODY CHARACTERISTICS: TEMPERATURE, DEPTH, SPECIAL CONDITIONS

	Airport	Water	Temperature Hi/Low (°F)	Depth (ft.)	Special Conditions				
					ICE	TID	CUR	TRA	MAR
LARGE	MIA	Blue Lagoon/Tamiami Canal	80/50	DP					
		Biscayne Bay/Atlantic Ocean	80/50	AV—DP		x		x	x
	BOS	Boston Harbor	75/32	AV—DP	x	x		x	
		Chelsea Creek	75/32	AV	x			x	
	MSP	Mother Lake	75/32	SH	x				x
		Lake Nokomis	75/32	-	x				
		Minnesota River/Gun Club Lake	-	-			x		
	SFO	San Francisco Bay	-	SH—AV				x	
	PHL	Delaware River	-	-			x	x	
	HNL	Keehi Lagoon	80/60	AV—DP				x	
		Pacific Ocean	80/60	DP		x		x	x
MED	DCA	Potomac River	80/32	AV	x		x	x	
	PDX	Columbia River	65/35	AV			x	x	
	PBI	Cloud Lake	-	AV					
		Palm Beach Inlet/Atlantic Ocean	-	AV—DP		x		x	x
SMALL	ORF	Little Creek, Chesapeake Bay	-	-				x	
		Elizabeth River	-	DP			x	x	
	SBA	East Channel	65/45	AV			x		
		West Channel	65/45	AV			x		

1. Symbol Depth Range
   - SH Less than 5 ft.
   - AV 5 - 12 ft.
   - DP Greater than 12 ft.
2. Symbol Description
   - ICE Icing
   - TID Tides
   - CUR Current
   - TRA Marine Traffic - Recreational/Commercial
   - MAR Marine Life
3. - Not Available

to address existence of ice, tidal action, currents, marine traffic, and marine life. Marine life can vary from sharks in the oceans to mosquitoes in the marshland, each requiring some degree of preparation by rescue personnel.

Water Rescue Vessels. Water rescue vehicles were categorized according to the guidelines stated in the water rescue plans AC. Appendix C shows the categories of water rescue vessels that can be considered part of a water rescue plan.

The size and number of vehicles required is very difficult to determine on a general basis. Many specific factors of the airport environment such as the ones listed in the previous paragraphs need to be considered to make a proper determination of the optimal fleet selection. Rescue over the water involves dealing with a dynamic terrain, and the most prudent choice depends on various factors including airport size, water depths and temperatures, the amount of traffic on the waterways, and the number of obstructions in terms of bridges and islands in the surrounding water.

Table 23 shows the rescue vessels available at the type W airports surveyed. For each airport, the number of conventional boats, rescue boats, airboats, amphibious vehicles, and fireboats are listed, along with their size and the number of crew and survivors that the vessels can be expected to carry.

Four of the six large airports had at least some fire-fighting capability among their water rescue vehicles. Only two of the eleven airports had extensive fire-fighting capability available through high capacity fireboats. The remaining four airports rely on portable pumps ranging in capacity from 125 to 600 gallons per minute (GPM). These pumps are mounted on the rescue boats and can use the underlying water for fire-fighting.

All but two of the type W airports surveyed had among its fleet at least one rescue boat or a conventional boat. Several had a combination of both. San Francisco, Boston, and Washington National had the most comprehensive fleets of all the airports surveyed.

Conventional boats can be considered the water-based equivalent of the ARFFs Rapid Intervention Vehicles (RIV) used for airport fire-fighting. These light boats typically have aluminum hulls or semi-rigid hulls with inflatable collars for flotation and can be used to get to the site of the accident quickly. If possible, they can even be used to deploy inflatable rafts for the first survivors. They can be used to survey the scene around the fuselage and communicate accident details back to the station. Rescue boats are typically larger (over 17 ft. in length) hull boats with the ability to provide some level of sustained rescue effort. They are sometimes equipped to provide shelter and emergency medical facilities. They are capable of carrying a lot of auxiliary equipment of the type described in appendix D.

Inland water bodies are often surrounded with low lying water, dry river beds, mud flats, and other topographic features which preclude the use of water rescue vessels with outboard motors. In these situations, airboats, amphibious vehicles, and helicopters could be used. Amphibious vehicles such as the "Hovercraft" in Washington National Airport's rescue fleet is capable of operation over land, snow, ice, mud, and sand as well as shallow or overgrown water areas. Amphibious vehicles have no surface contact steering and no brakes and hence require special training for use. The airport typically specifies the custom features required on the vessel so that it can serve for water rescue missions. Airboats are powered by a large hull-mounted propeller and can be used effectively in marshy terrain.

TABLE 23. RESCUE VESSELS AT TYPE W AIRPORTS

		Conventional Boats			Rescue Boats			Airboats			Amphibious			Fireboat		Helicopters	
		Qty	Size	Cap	Qty	Size	Cap	Qty	Size	Cap	Qty	Size	Cap	Size	GPM	Qty	Cap
LARGE	MIA[a]	2	12', 16'	6, 8	1	28' (ff)	29										
	BOS	2	14'	6	2	22', 30' (ff)	12,20							80'	6000		
	MSP							1	20'	12							
	SFO	4	12'	4	1	26' (ff)	15				1[c]			40'[d]	2500		
	PHL	1	14'	2	1	24' (ff)	3										
	HNL	1	12'	2	1	21'	12										
MED	DCA	1[b]	17'	7	2	22' (ff), 29' (ff)	11, 12	1	22'	7	1	20'	7				
	PDX				1	27' (ff)	24										
	PBI															3	4
SMALL	ORF	1	18'	6													
	SBA	1	17'	7													

Qty: Quantity
Size: Length in ft.
Cap: crew + passenger carrying capacity
ff : Equipped for limited firefighting

(a) All vessels stored off airport property, 7 miles away, at Marine Division site.
(b) To be replaced by 22' Boston Whaler Rescue Boat
(c) In process of acquiring custom designed amphibious vessel
(d) Custom designed to serve for rescue and firefighting.

Water Rescue Equipment. There is a vast variety of rescue equipment that can be used for SAR situations in the water. Since it was difficult to get a detailed inventory from each airport, only some of the principal water rescue equipment was considered for the survey. A listing of many of the other types of water rescue equipment available to airports is given in appendix D.

The type and quantity of water rescue equipment varied from airport to airport. Table 24 is a listing of the water rescue equipment at the type W airports. The number and passenger capacity of flotation platforms (similar to life rafts), size, number, and capacity of life ramps (an extended reach flotation/rescue device), wave runners (or jet skis), anti-exposure suits, flotation air hoses, and portable pumps and their capacity in GPM are all shown in the table.

TABLE 24. MAJOR WATER RESCUE EQUIPMENT AT TYPE W AIRPORTS

		Float Platforms		Life Ramps			Wave Runners	Anti-exposure Suits	Flotation Air Hose	Portable Pumps	
	Airport	Qty	Cap	Qty	Size	Cap	Qty	Qty	Availability	Qty	GPM
	MIA						2		x	1	-
	BOS	16	25	2	80'	64		>15		1	600
L				2	50'	36					
A				2	30'	24					
R	MSP	4	10					6	x		
G	SFO	10	20	2	50'	36	2		x	1	250
E	PHL	2	25								
	HNL	2	25								
	DCA	1	30	4	30'	24		6	x	1	250
		12	10								
M	PDX	4	25	3	50'	36		8	x	1	125
E				1	30'	24					
D	PBI	2	50						x		
		3	25								
S	ORF								x		
M	SBA			1	50'	36					
L											

As with water rescue vessels, the type and quantity of rescue equipment appropriate for a particular airport is also a function of many factors, and it is difficult to generalize or estimate which is the correct type or quantity of equipment that should be on an airport's inventory.

Reference 7 recommended that airports have a minimum water rescue capacity equal to the capacity of the largest aircraft expected to land at that airport. The information from tables 23 and 24 was used to estimate the rescue capacity at the Type W airports. Table 25 shows the

TABLE 25. ESTIMATED MINIMUM RESCUE CAPACITY

Airport	Airport Size	Rescue Capacity			Total
		Vessels	Equipment		
			Float Platforms	Life Ramps	
BOS	L	44	400	242	686
SFO	L	31	200	72	303
DCA	M	44	150	96	290
PDX	M	24	100	132	256
PBI	M	12	175	0	187
HNL	L	14	50	0	64
PHL	L	5	50	0	55
MSP	L	12	40	0	52
MIA	L	43	0	0	43
SBA	S	7	36	0	43
ORF	S	6	0	0	6

rescue capacity of the airports based on the rescue vessels and flotation devices such as the platforms and the life ramp. The airports are listed in order of decreasing rescue capacity. For the airports surveyed, Boston-Logan International Airport, San Francisco International Airport, and Washington National Airport have the largest rescue capacity. In general, the bulk of the rescue capacity comes from flotation equipment and is probably further augmented by life vests which are not included in the table. Figure 8 compares the Type W airports and their ARFF index against the passenger carrying capacity of the largest aircraft expected to serve airports of index E, D, and C. Only Boston-Logan International Airport, Washington National Airport, and Portland International Airport (Oregon) meet or exceed the recommended rescue capacity. However, the actual rescue capacity at a given airport may be enhanced by pooling resources from mutual-aid agencies, as is the case in almost all airports in the study.

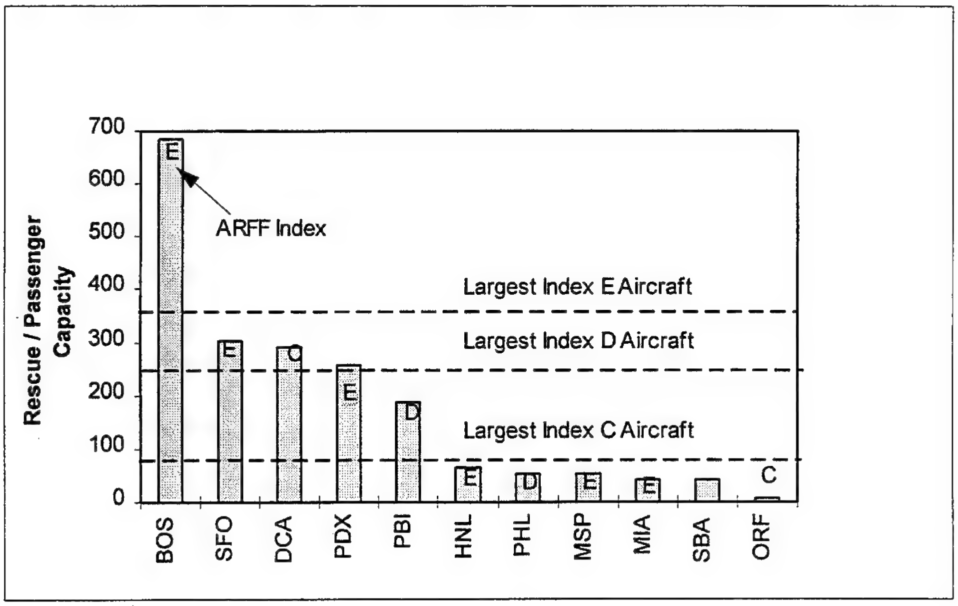


FIGURE 8. COMPARISON OF AIRPORT RESCUE CAPACITY AND AIRCRAFT PASSENGER CAPACITIES

Operations.

Rescue Facilities. The rescue facilities for water rescue at airports typically fall under the jurisdiction of the main fire rescue operations at the airport. Therefore, there were generally no dedicated water rescue facilities as such at the airports in the survey. In all cases, the personnel and operations were centralized to the main fire and rescue station and any satellite fire stations at the airport. Some airports had a special boat house or docking facility where the rescue vessels could be stored in the water, thereby enabling faster response. Washington National Airport, for example, has multiple storage and launching sites which provide for increased accessibility to the water and could provide faster response depending on the location of the accident. In some cases, the vessels were kept on trailers at the main station and were intended for deployment using designated boat-ramps. Table 26 identifies the airports with vessels in water and those with vessels on trailers. Only 36 percent (4 of 11) of the type W airports surveyed had facilities where rescue vessels were maintained in the water. Two of the airports, Philadelphia International Airport and San Francisco International Airport currently have plans under way to build such facilities, which would increase the number to just over 50 percent.

Response Times. The estimated response times are also given in table 26. The response time is the time required to deploy rescue personnel in the water from the time the alert is issued. These figures are only estimates, since the actual response is a strong function of many factors such as weather conditions, time of day, and personnel availability. Some airports were able to provide a reasonably accurate figure based on live drills and table top exercises, some were purely an estimate, while still others were not able to provide an estimate. The average response time for airports with vessels located in the water was found to be 3.6 minutes. Response time for airports with vessels requiring towing from the station and then launching in the water was found to be an average of 8.4 minutes. These numbers clearly demonstrate the improvement in response time gained by maintaining rescue vessels in the water.

TABLE 26. RESCUE VESSEL LOCATION AND RESPONSE TIMES

	Airport	Water Body	Rescue Vessels			Distance from Rescue Facility	Estimated Response Time
			In-Water	On-Airport	No Response		
LARGE	MIA	Blue Lagoon/Tamiami Canal			x	n/a	n/a
		Biscayne Bay/Atlantic Ocean	x			0	-
	BOS	Boston Harbor	x			0	2 min
	MSP	Mother Lake		x		1.6 mi	20 min
		Lake Nokomis, Minn River			x	n/a	n/a
	SFO	San Francisco Bay	*	x		0	-
	PHL	Delaware River	*	x		2500 ft	5 min
	HNL	Keehi Lagoon		x		-	5 min
		Pacific Ocean		x		-	7 min
MED	DCA	Potomac River	x			0	4 min
	PDX	Columbia River	x			0	5 min
	PBI	Cloud Lake		x		2400 ft	-
		Palm Beach Inlet/Atlantic Ocean		x		2 mi	-
SML	ORF	Little Creek, Chesapeake Bay		x		3200 ft	5 min
		Elizabeth River			x	n/a	n/a
	SBA	East Channel		x		4300 ft	7 min
		West Channel		x		350 ft	-

* Boat House planned
\- Not available
n/a Not applicable

Personnel. The training level of water rescue personnel was found to vary vastly from airport to airport and was therefore not quantified. Instead, a list of comprehensive training topics specific to water rescue is presented here:

- Marine rescue/rescue swimming. Certified in training for rescuing survivors in different situations.
- Airport familiarization. To address the water environment, seasonal changes, special conditions, marine life, and other factors discussed earlier.
- Aircraft familiarization. Including current training in aircraft dimensions, emergency exits, emergency equipment location and operation, and the deployment and use of vests, rafts, and slides.
- Diving.
- Victim extrication. To shore as well as to the rescue boat.
- Rescue vessel operation. Including special skills required to operate (launch and recover) amphibious vehicles and airboats.
- Personnel safety equipment operation and maintenance. Including flotation platforms, ice rescue suits, portable pumps, etc.
- Swift water rescue. To include training in the rescue techniques in fast moving water and operation of the special tools required.
- Emergency medical treatment. For medical situations such as hypothermia and fuel/vapor ingestion.
- Hazard preparation. To deal with special situations with aircraft in the water such as loose hydraulic lines, control cables, baggage, and contaminated water.
- Marine communications and radar use.

Table 27 shows the number of personnel that are on duty at the type W airports surveyed. The number of people on a regularly scheduled basis as well as the number at minimally staffed times are indicated. The average number of rescue personnel at large airports was found to be 13.6 and 10.6 at regular and minimal staffing levels. The shift systems and the breakup of the rescue teams were extremely different at each airport and are not presented here. The percentage of dedicated water rescue personnel among the ranks was not surveyed, but it was found in all cases that at least some part of the rescue team was comprised of water rescue people even in minimally staffed shifts.

TABLE 27. RESCUE PERSONNEL AVAILABILITY

Airport Size	Airport	Personnel Availability	
		Regular	Minimal
L	MIA	3	0
L	BOS	18	13
L	MSP	10	8
L	SFO	17	17
L	PHL	17	15
L	HNL	17	11
M	DCA	17	14
M	PDX	8	8
M	PBI	12	7
S	ORF	6	4
S	SBA	3	3

<u>TYPE N AIRPORTS</u>. As mentioned earlier, type N airports were defined as airports with little or no water rescue effort on airport property and almost complete reliance on mutual aid agencies. The requirements for water rescue capabilities of airports are addressed in FAR Part 139.325 "AEPs." It requires the certificate holders (airports) to have an airport rescue plan, part of which states the airport "shall have provisions for water rescue from a significant body of water adjacent to the airport which is crossed by the approach and departure flight paths of the air carriers." Reference 7 states that:

> " if the significant body of water is located off airport property, it is very likely the airport will not be the primary response agency. In such cases, it is the responsibility of the airport to ensure that the appropriate rescue agencies are formally notified of the possibility of an aircraft accident in the significant body of water."

This relieves even those airports that are immediately adjacent to bodies of water (Los Angeles International Airport, Anchorage International Airport, Kahului Airport, and Portland International Jetport are such examples in the present survey) from serving as the primary response agency.

Reliance on mutual aid is a viable option; however, concerted effort is required on the part of the airports that such reliance will provide prompt response to actual emergencies. In the 1989 rejected takeoff of a Boeing 737 at LaGuardia Airport in New York, the aircraft ended up in the waters of the Bowery Bay. The first boat did not arrive on the scene till ten minutes after the accident [3]. The boats were sent by a mutual-aid agency, the New York Police Department Harbor Unit. This response time is in stark comparison to the mandated response time on airport movement areas where rapid intervention vehicles (RIVs) are required to be available at the farthest point on the airport within three minutes (FAR Part 139.319).

Table 28 lists the 12 type N airports. It outlines the neighboring bodies of water and the distance separating the water and the end of the runway closest to the water body. The total number of runways and the percent of runways for which the approach or departure would occur over the water are also identified. The percentage of runways with overwater approach were found to vary from 33 to 67 percent, with an average of 46 percent. In contrast, the percent of runways with overwater approaches for type W airports as shown in table 21 ranged from 50 to 100 percent with an average of 77 percent for the 11 airports.

Reference 7 recommends that the airports maintain support inventories and conduct frequent exercises to affirm water rescue efforts are in place. The inventory should be part of the water rescue plan which should state exactly what services, equipment, and capabilities are to be available from all mutual-aid agencies. The nature of support inventories was found to vary vastly. At some airports no support inventories were maintained and at others it was merely a list of phone numbers and contact names and at others sometimes there was a brief description of the vessels inventory. Table 29 shows the type N airports and their present status on maintaining support inventories for water rescue. Forty-two percent (5 of 12 airports) had some form of support inventory addressed as part of their AEP. An example of the most comprehensive inventory among these surveyed airports was at Little Rock National Airport and is presented in appendix E as extracted from the AEP.

WATER RESCUE TECHNOLOGIES.

This section describes some of the technologies in use at the various airports surveyed.

One of the newer pieces of rescue equipment used by several public safety groups is an innovative device called the Life-Ramp developed by Innovative Safety Systems, MA. The company provides a custom version for airport water rescue called the Life-Ramp-II©. Figure 9 is a schematic of the device showing its salient features. The device is a portable platform that can be carried to the site of the accident and then inflated using conventionally available compressed air sources such as a fire truck. It can be used on several types of terrain including ice, snow, and mud. The device inflates to provide a long narrow platform of lengths ranging from 30 to 80 ft. Rescue personnel can then traverse the length of the platform to reach out to survivors and provide assistance. The device also provides survivors with emergency flotation.

TABLE 28. TYPE N AIRPORTS: WATER ENVIRONMENT, DISTANCES, AND RUNWAYS

	No.	Airport name	ID	Water Environment	Distance	Total Runways	% App/Dep Overwater
	1	Los Angeles International	LAX	Pacific Ocean	3,000 ft	4	50
L	2	Seattle-Tacoma Int'l	SEA	Puget Sound, Elliot Bay	1.9 mi. *	2	50
G	3	Salt Lake City International	SLC	Great Salt Lake	2.2 mi	3	33
	4	Anchorage International	ANC	Cook Inlet	1,400 ft	3	67
M	5	General Mitchell Int'l	MKE	Lake Michigan	2.9 mi	3	50
E	6	Kahului Airport	OGG	Pacific Ocean	1,500 ft	2	50
D	7	Little Rock National Airport	LIT	Arkansas River	3,300 ft	2	50
	8	Albany County Airport	ALB	Mohawk River	1.3 mi	2	25
	9	Portland Int'l Jetport	PWM	Fore River/Casco Bay	1,300 ft	2	50
S	10	Pensacola Regional	PNS	Gulf of Mexico	1.2 mi	2	50
M	11	Mahlon Sweet Field	EUG	Fern Ridge Reservoir	1.5 mi	2	25
L	12	Quad City Airport	MLI	Rock River	4,000 ft	2	50

* Perpendicular to runway approach

TABLE 29. TYPE N AIRPORTS: MUTUAL AID AND SUPPORT INVENTORY

		Primary Response Agency	Support Inventory	
	ID	(Mutual Aid)	Maintained	Not Maintained
L	LAX	L.A. County Lifeguards, USCG		X
G	SEA	King County FD, Seattle FD	X	
	SLC	Utah Parks and Recreation Dept.		X
M	ANC	USCG, International Air Guard		X
E	MKE	South Milwaukee FD	X	
D	OGG	City and County of Maui, USCG		X
	LIT	Pulaski County Sheriff	X*	
S	ALB	Sheriff's Office, Airport Detail		X
M	PWM	City of Portland FD, USCG	X	
L	PNS	USCG, Navy Sea/Air Rescue		X
	EUG	Eugene FD		X
	MLI	Rock Island Sheriff's Dept.	X	

Note: Reference figures E-1 and E-2 for a sample support inventory and operations chart.

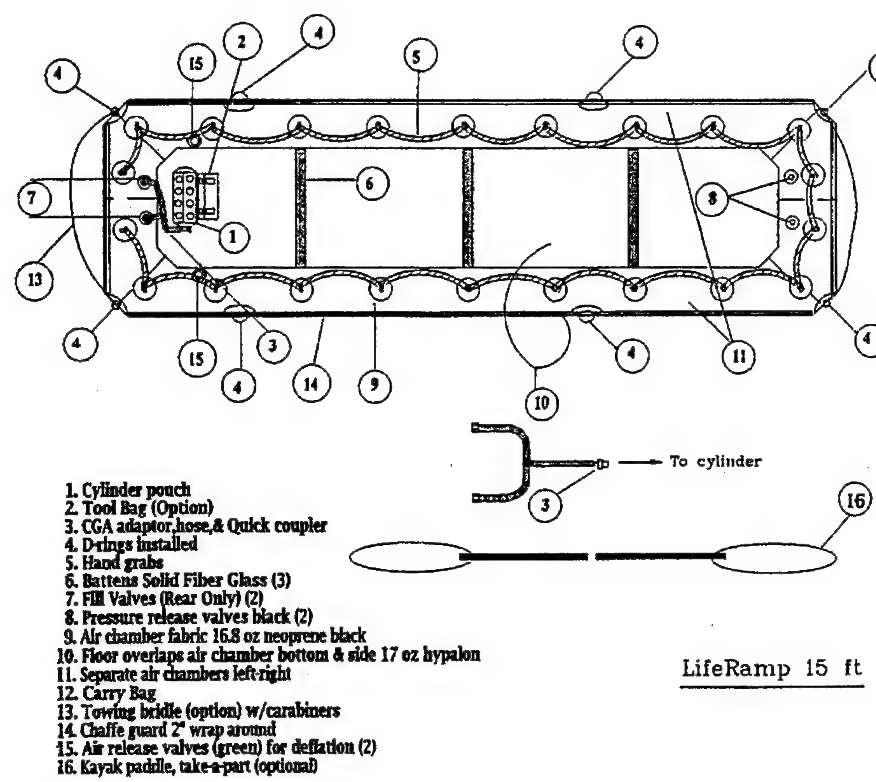


FIGURE 9. SCHEMATIC OF 15-FOOT LIFE-RAMP©

The device can be rowed like a raft, and hardware for towing the device to safety is also included. Table 24 lists some of the airports that use the device. The capacity for rescuing large number of victims is also a good feature of the device.

A similar device made by an overseas manufacturer called the "Rescue Path" was also being considered by some of the airports during the course of the survey. This device is akin to a stiff inflatable mat that can be laid out over a large expanse of ice, water, mud, or any unstable terrain. Its primary aim is to provide extended reach for rescue personnel. Some of the rescue teams have used their fire-fighting hoses for flotation by capping the end of the fire hose and filling it with compressed air. Fed out over the water, the hose can provide hundreds of feet of flotation support for survivors. Both 3- and 5-in.-diameter hoses were being used in drills. Table 24 indicates the airports that use the technique. It was found that the technique is generally more popular in warmer climates because of problems with using such a method in freezing conditions.

Innovations in rescue vessels were also found. One features the use of water jet propulsion. As an alternative to conventional inboard or outboard propeller based engines, water jet propelled engines have some noteworthy advantages. An obvious one is the absence of fast moving metallic propellers that can pose a significant hazard to survivors in the water. Water jet propelled engines are also very agile, capable of quick maneuvering, and have superior stopping capability. Advances in hull design and materials are producing faster, more efficient rescue vessels.

SECTION 3. EMERGENCY FLOTATION EQUIPMENT

INTRODUCTION.

The impact of a large transport aircraft into water immediately brings into play a large number of safety systems. Survival of the occupants depends on the performance of those systems, which vary in function and complexity ranging from the fuselage and its flotation characteristics to the plastic packaging used to hold emergency PFDs. This section of the study describes emergency equipment that could likely be used by the occupants involved in a transport water accident. The items that fall under this category are

- PFDs,
- life preservers,
- life rafts,
- emergency evacuation slides, exit ramps, slide/ramp combinations, and
- ditching lines.

Note that PFDs and life preservers are listed separately because there are two different classes of flotation devices for individual use. Although similar in form and function, PFDs are typically of lower performance than the life preservers. In addition, flotation seat cushions and head rests that serve other primary functions on board the aircraft all fall in the category of PFDs. The difference between the two types of individual flotation is clarified in this section.

The effectiveness of life preservers, PFDs, slides, and rafts can play a vital role in the survival of the occupants. The need to keep survivors afloat and out of the water can be seen by observing the hazards of exposure in the water. Table 30 shows that the estimated survival time depends on the water temperature [7].

TABLE 30. SYMPTOMS OF EXTENDED EXPOSURE TO WATER AT DIFFERENT TEMPERATURES

Symptom	Temperature (°F)	Time (Min.)
Loss of use of hands and forearms	38	15
	48	20
	70	180
Loss of mental activity	38	45
	48	60
	70	270
Hypothermia and death	38	65
	48	90
	70	360

There are two major problems that occur from cold water immersion, even if a life preserver is in use. The first is gasping or sharp intake of breath due to the shock of cold water on the skin. If this happens under water, it creates a potential drowning situation. The second problem is from extended exposure. Most people can lose up to 5.5 degrees of body temperature safely, but as the body temperature drops below 93°F, a loss of mental and physical functions is likely, followed by loss of consciousness. The solution to the first problem is to wear flotation gear that keeps the head out of the water and possibly to wear flotation clothing that reduces the cold-water shock. If prolonged exposure is inevitable, the chances for survival can be improved by putting the body in a fetal position and reducing heat loss which occurs mainly from the armpits, groin area, feet, and head.

Due to the inherent differences in the nature and function of each of the flotation devices mentioned, they will be discussed separately. The regulations governing the design and certification of flotation devices were surveyed. First the regulations pertaining to the requirement, quantity, capacity, design, certification, and maintenance of flotation devices as prescribed in the FARs are presented. Next, the detailed design, performance, testing, and certification requirements as required for Technical Standard Orders (TSOs) certification are discussed. The certification procedures of the flotation devices are considered including approval, maintenance, and testing of the devices.

A technology survey of the flotation devices contains information outlining the materials employed, physical features, and operating performance of each device. This is followed by recommendations regarding improvements in design, standards, procedures, and regulations.

There are two major domestic manufacturers of slide and slide-raft assemblies. Because of the proprietary nature of the data for these devices, it was not possible to collect comprehensive data. Hence, a technology survey was not presented and, similarly, no resulting recommendations were presented. Nevertheless, a thorough review of regulatory design and performance requirements is still presented.

REGULATORY REVIEW.

The documentation governing the requirements, design, construction, and certification of the emergency equipment mentioned is available in terms of Technical Standard Orders (TSOs), and FARs, both issued by the FAA. Additional documentation is also available in terms of requirements issued by the U.S. Coast Guard and MIL-STD specifications issued by the Department of Defense. U.S. Coast Guard and MIL-STD specifications are not specifically directed towards safety equipment used in commercial aviation; therefore, they are not considered here.

The FARs frequently state the requirement for the use of approved flotation equipment. The word "approval" used in the context of the FARs typically refers to TSO approval. This means that manufacturers meet the criteria of the TSO in order to get their brand of flotation equipment approved or TSO certified.

FEDERAL AVIATION REGULATIONS. The FARs that regulate flotation devices on transport aircraft are in CFR 14, parts 25, 121, 125, and 135 as seen in appendix F. The various FAR parts sometimes contain overlapping regulations for each device. All the applicable FARs for each type of device are discussed in this section. For the title of each of the referenced FARs, see appendix F.

For each device, except the lifelines, the applicable FARs are discussed in separate sections. Lifelines are required only per FAR 25.1411. It requires that there must be one on each side of the fuselage and they must be arranged to allow occupants to stay on the wing after ditching. Lifelines are also mentioned in FAR 135.311, which describes required training of crew members in the use of lifelines.

Life Preservers and Personal Flotation Devices. Approved life preservers are only required for EOOs according to FARs 135.167, and 121.339. EOOs covered by FAR 125.209 do not require a life preserver; a PFD is sufficient for compliance. In fact, FAR 121.340 allows for operation without any means of personal flotation if it can be proved to the Administrator that the water over which the aircraft operates is not large or deep enough to warrant use of flotation devices. Also under FAR 25.1415, a PFD or a seat cushion will suffice if the aircraft is not ditching certified. Following are the specific FARs pertaining to life preserver and PFD storage, features, training, and inspection:

FAR	Stowage
25.1411	Location must be obvious and be such that device is directly accessible. Device must be within easy reach of a seated occupant and protected from inadvertent damage.
121.309	Emergency equipment must be accessible to crew or passengers where applicable.
121.339	Life preservers and emergency location transmitters (ELTs) must be easily accessible in the event of a ditching without appreciable time for preparatory procedures. Must be installed in conspicuously marked, approved locations.
135.167	Life preservers must be installed in conspicuously marked locations and be easily accessible to occupants in a ditching. (Same per FAR 125.207)

FAR	Features
135.167	Life preservers for EOO must be equipped with approved survivor locator lights. (Same per FAR 121.339)

<u>FAR</u>	<u>Training</u>
135.311	Individual instruction must be provided to each crew member in location, function, and operation of all emergency equipment. Drills must include donning and inflation of life vests and other individual flotation devices.

<u>FAR</u>	<u>Briefing</u>
125.327	If flight is EOO, then briefing on ditching procedures and use of required flotation devices must be given.

<u>FAR</u>	<u>Demonstration</u>
125.189	Demonstration of emergency evacuation procedures are given in detail in an appendix to this part.

<u>FAR</u>	<u>Inspection</u>
121.309	Each flotation device must be inspected regularly in accordance with operations specifications to ensure its condition for serviceability and readiness.

<u>Life Rafts</u>. Life rafts are only required for flights conducting EOOs. Only approved life rafts can be used to comply with FAR 25.1415.

<u>FAR</u>	<u>Stowage</u>
25.1411	Must be stored near exits. Stowage must be provided to accommodate all rafts required to carry maximum number of occupants. Stowage must be so as to allow for use of rafts at other than intended exits.
135.167	Rafts must be installed in conspicuously marked locations and be easily accessible to occupants in a ditching situation.
121.309	Emergency equipment must be accessible to crew or passengers where applicable.
121.339	Life rafts must be easily accessible in the event of a ditching without appreciable time for preparatory procedures. Must be installed in conspicuously marked, approved locations.

FAR	Quantity
25.1415	Rafts must be sufficient to provide buoyancy and seating for all occupants, even if one raft of largest capacity is rendered unusable. (Same per FAR 121.339)
135.167	Rafts of sufficient capacity and buoyancy to accommodate occupants of the aircraft.
125.209	Enough rafts to carry all occupants must be provided.

FAR	Features
25.1411	Must have a static line for attachment to the airplane.
25.1415	Each raft must have a trailing line and a static line designed to hold raft near airplane but to release if airplane becomes totally submerged.

FAR	Auxiliary equipment
25.1415	Approved survival equipment must be attached to each raft. An approved emergency locator transmitter (ELT) must be available in one raft.
135.167	A list of required auxiliary equipment is given. See appendix G for details.
135.167	An approved ELT is required. (Same per FAR 121.339)
125.209	A list of required auxiliary equipment is given. See appendix G for details.
125.209	An ELT attached to one of the rafts.
121.339	At least one pyrotechnic signaling device and survival for each raft.

FAR	Training
135.311	Drills must include removal and inflation of life rafts.

FAR	Briefing
125.327	If flight is an EOO, then briefing on ditching procedures and the use of rafts must be given.

FAR	Demonstration
121.291	Each raft is removed from stowage. One raft is to be launched and inflated and crew members are to display and describe the use of each item of required emergency equipment.

FAR	Inspection
121.309	Each raft must be inspected regularly in accordance with operations specifications to ensure its condition for serviceability and readiness.

Slides. Each type W exit and each nonoverwing exit must have a means to assist occupants to the ground according to FAR 25.810 and FAR 125.207. The following list describes the specific FARs that pertain to the requirements on quantity, features, and testing of slides.

FAR	Quantity
25.810	One at each type W exit (42 x 72 in.) and each nonoverwing exit higher than 6 ft. off the ground.
25.810	Escape route (exit ramp) must be established from each overwing exit, which must be covered with a slip resistant material (except for surfaces suitable as slides). If the escape route leads to a position on the wing 6 ft. or higher from the ground, means must be provided to assist evacuees to the ground (slide/ramp combination).
121.310	Each nonoverwing exit more than 6 ft. from the ground must have an approved means to assist occupants in ascending to the ground.

FAR	Stowage
25.1411	Must be stowed at exits for which they are intended.
121.309	Slides must be accessible to crew or passengers where applicable.

FAR	Features
25.810	Type W exit slides must be capable of carrying two lines of evacuees simultaneously. They must be automatically deployed and must be erected within 10 seconds after deployment. They must be self-supporting and provide for safe evacuation even after failure of the landing gear. They must withstand 25-knot winds from any direction.

121.310	An assisting means that deploys automatically must be armed during taxiing, takeoff and landing.
<u>FAR</u>	<u>Testing</u>
25.810	Five continuous deployment and inflation tests must be conducted with at least three on the same test sample.
<u>FAR</u>	<u>Training</u>
135.311	Drills must include use and deployment of emergency chutes (slides).
<u>FAR</u>	<u>Demonstration</u>
121.291	Fifty percent of the exit slides on the aircraft or mock-up to be deployed by the flight attendants. The slides will be selected by the administrator and must be ready for use within 15 seconds. (See appendix J for details).
<u>FAR</u>	<u>Inspection</u>
121.309	Each slide must be inspected regularly in accordance with operations specifications to ensure its condition for serviceability and readiness.

<u>TECHNICAL STANDARD ORDERS</u>. The FARs summarized in the previous section are the very minimum requirements for flotation devices. In order for a flotation device to comply fully with the FARs, it must be certified in accordance with the specifications of the applicable TSO.

In addition to providing guidelines for the detailed design and performance of the devices, the TSOs also outline other requirements. Manufacturers are required to provide the Aircraft Certification Office which issued the TSO with a detailed set of data including

- operating instructions and limitations;
- packing instructions and limitations;
- a complete description of the device, including detailed drawings, materials identification and specification, and installation procedures;
- TSO qualifications test report;
- applicable installation limitations, including stowage area temperatures;
- maintenance instructions, including instructions regarding inspection, repair, and stowage of materials; and

- functional test specifications to be used to test each article to ensure compliance with the TSO.

Table 31 shows the TSOs that are described in the present study. It includes subsystems such as survivor locator lights and ELTs. Note that there are no TSOs governing the design of ditching lines.

TABLE 31. LIST OF TECHNICAL STANDARD ORDERS FOR EMERGENCY FLOTATION EQUIPMENT

TSO #	Title
C13f	Life Preservers
C72c	Individual Flotation Devices
C70a	Life Rafts (reversible and nonreversible)
C12c	Life Rafts (twin tube)
C69b	Emergency Evacuation Slides, Ramps, Slide/Raft Combinations
C85	Survivor Locator Lights
C91a	ELT (now withdrawn)

For comparison, further design, and performance criteria see AIR STD document 61/4 entitled "Flotation and Sea Survival, Test Method and Requirements," [10]. The standard applies to life vests used in defense applications.

TSO C91 for ELTs has been withdrawn due to problems with ELTs manufactured under the order. An improved TSO is in process to address safety recommendations made by the NTSB and the SAR community. The new TSO is expected to dramatically reduce ELT activation failures and increase the likelihood of locating planes after accidents.

Technical Standard Orders C-13, C-72: Life Preservers and Personal Flotation Devices. Details of TSO C-13 and C-72 are summarized in appendix H. The versions reviewed in the present study are dated September 24, 1992, (TSO C-13f) and February 19, 1987, (TSO C-72c), respectively. TSO C-85 applies to survivor locator lights, which are required on life preservers as per FARs 135.167 and 121.339, and TSO C-85 is also summarized in appendix H.

Technical Standard Order C-70: Life Rafts. TSO C-70 is summarized in appendix I. TSO C-12 is an older version of C-70 dated May 1961. TSO C-70a dated April 13, 1994, is the more recent and comprehensive of the two and is reviewed here.

Technical Standard Order C-69: Emergency Evacuation Slides, Ramps, Slide/Raft Combinations. TSO C69 is summarized in appendix J. The most recent version, TSO C-69b dated August 17, 1988, is reviewed here.

TESTING AND CERTIFICATION. For each of the flotation devices described in this study, detailed test requirements were found in the applicable TSOs. Every manufacturer has to demonstrate that the device performs in accordance with the TSO testing requirements.

Life Preserver Certification Tests.

- Material Tests. Test for aging, tensile and tear strength, adhesion, permeability, and flammability are to be performed in accordance with approved federal test methods stated in the TSO.

- Leakage Test. The preservers flotation chambers must not lose more than 1/2 psig pressure in less than 12 hours.

- Overpressure Test. The preserver's flotation chambers must withstand at least 10 psig for at least five minutes.

- Submersion Test. The required buoyancy must be maintained for up to eight hours after submersion in 72°F water.

- Salt Spray Test.

- Inflator Test. The required force for inflation must not exceed 15 lb. The pull cord must also be within approved strength limits. The inflation cylinder must also meet specified criteria. The mechanical inflation valves must be within required leakage limits.

- Jump Test. The preserver must remain attached and not cause injury to the wearer when the subject jumps from a height of five ft. into water. A similar test is prescribed for infant preservers where the adult jumps into the water carrying the infant preserver.

- Donning Tests. Twenty-five test subjects are required in the prescribed age and sex groups. The subjects are to be seated with seat belts on in a mock-up coach class of a typical aircraft. The test is timed beginning with the life preserver in the subject's hand and in its storage packet. The test ends when the life preserver is donned and secured. The test is passed when 75 percent of total subjects and 65 percent within each age group complete the test in less than 25 seconds. Similar tests for infant life preservers require five subjects donning life preservers on infant dummies. The test is passed when 60 percent of the adults complete the assisted donning in less than 90 seconds.

PFDs are required to pass similar versions of the submersion and salt spray tests as well as a test for extreme temperature functioning. Donning tests are not required for PFDs.

Life Raft Certification Tests.

- Pressure Retention Test. Pressure must not fall below minimum operating pressure in less than 24 hours

- Overpressure Tests. The rafts must be able to withstand 1.5 times the maximum operating pressure for at least five minutes.

- Water Tests. It must be demonstrated that rated and overload capacities can be met with one inflation chamber in operation at minimum pressure. Freeboard must still be at least equal to the value prescribed in the TSO. Persons used in the test must have an average weight of at least 170 lb. and must be wearing a life preserver during the test. Required emergency equipment must be on board during the test. The raft must be shown to be self-righting, or be able to be righted by one person while in the water.

- Boarding Test. A test to verify functioning of boarding aids must be done.

- Sea Trials. These tests can be done in the field or modeled by analysis. The life raft must be able to withstand 27-knot winds and waves of 10 ft. Deployment tests to simulate deployment from an aircraft must be conducted.

- Canopy Test. Tests must show that the canopy is resistant to tearing and can be erected by a single person or in a raft filled to rated capacity.

- Drop Test. The life raft in its package must be dropped onto a hard surface from a height of five ft. and still be able to function.

- Portability Test. The test must prove that the raft can be retrieved from storage by no more than two persons and be deployed at any suitable exit.

- Carrying Case Test. Carrying case must open and allow satisfactory deployment at least 10 times.

- Gas Cylinder Release. The gas cylinder must release by pulling the ripcord from any position.

- Temperature Test. Minimum and maximum temperatures for satisfactory performance should be determined. Detailed test procedures are stated in the TSO.

Slide and Exit Ramp Certification Tests.

- Performance Test. At least five consecutive deployment and erection tests must be conducted without failure.

- Pressure Retention Test. In no less than 10 separate demonstrations, 200 persons must evacuate the aircraft using the slide at an average rate of at least one person per second.

- Overpressure Test. The slides must be able to withstand 1.5 times the maximum operating pressure for at least five minutes.

- Leakage Test. The pressure must not fall below 50 percent of nominal operating pressure in less than 12 hours.

- Material Tests. Test for aging, tensile and tear strength, adhesion, permeability, and porosity are to be performed in accordance with approved Federal Test Methods stated in the TSO.

- Radiant Heating Test. The TSO lists the apparatus required to test resistance to radiant heating. The minimum time required to resist failure after exposure to a specified level of radiant heat flux is specified.

Slide/Raft Combination Certification Tests.

- Functioning. The separation of the slide/raft from a simulated aircraft installation must be demonstrated.

- Stability Test. Stability of the raft must be demonstrated at rated capacity and at 50 percent rated capacity.

In addition to the tests stated for rafts under TSO C-70, TSO C-70 also applies to slide rafts operating in the raft mode.

FLOTATION DEVICE STUDY.

The information for the study was obtained from sales and technical literature, media articles, and discussion with vendors' representatives. In some cases, information was obtained from aircraft maintenance manuals and airlines' facilities and planning documents.

PERSONAL FLOTATION DEVICES. PFDs are mainly divided into two categories: inflatable (type-I), and noninflatable (type-II). The inflatable life vest is the most widely used and can be described as essentially a yoke-shaped ring of air that surrounds the wearer's neck and provides buoyancy to keep the person afloat. The noninflatables are typically foam seat cushions and

pillows that serve other primary functions on board. The inflatable types are further classified as Personal (or Individual) Flotation Devices and Life Preservers. Life preservers are typically double cell vests which meet more stringent design and performance requirements for EOOs. Figure 10 depicts a typical C-13 life preserver and a C-72 life vest.

The characteristics of those carried on transport aircraft are determined primarily by the requirements of the TSO C-13 (Life Preservers) and TSO C-72 (PFDs). TSO C-13 is more stringent in terms of requirements and performance than TSO C-72. Within TSO C-72, type-I refers to single cell, reduced buoyancy inflatable vests which are similar in shape to the TSO C-13. Type-II PFDs typically refers to flotation seat cushions that are made of closed cell foam. Table 32 lists the different features of life preservers and inflatable PFDs:

TABLE 32. COMPARISON BETWEEN LIFE PRESERVER AND INFLATABLE PERSONAL FLOTATION DEVICE

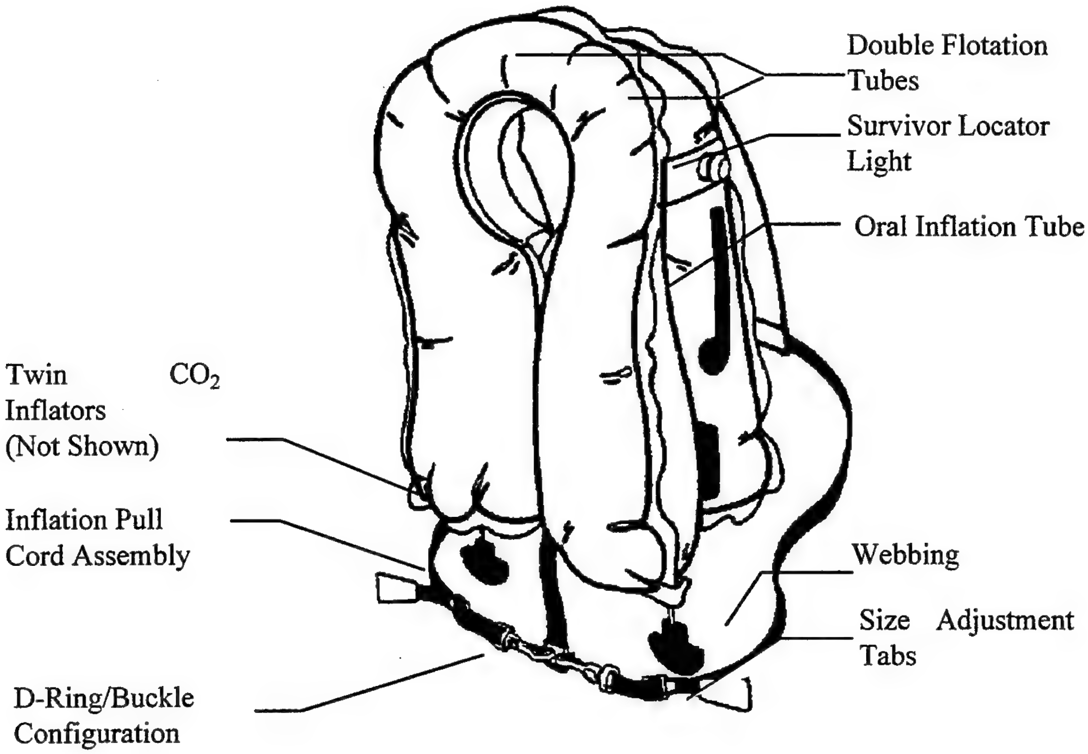
Feature	C-13 (Life Preserver)	C-72 (PFD)
Minimum Buoyancy	36 lb.	14 lb.
Self-Righting	Yes	No
Float Chambers	Two[1]	One
Locator Light	Yes	No
Donning Tests	Yes	No

[1] Not required in TSO C-13, however this feature is generally incorporated in order to meet buoyancy requirements.

The variety of life vests available range from the generic marine vest used for recreational boating to the most advanced for military applications. The differences are primarily in materials, performance, features, and accessories. Manufacturers of aviation life vests design them to meet the requirements of the applicable TSOs. Hence, the main features of the vests are the same, with subtle differences in performance and quality.

Features. The salient features of a typical C-13 preserver are discussed in terms of materials used, the physical and functional qualities, and the performance of the device. The bulk of the vest is comprised of a water proof, brightly colored, flame resistant shell. Nylon webbing is attached to the shell and is used to attach the preserver to the user by means of a variety of fastening methods are shown in figure 11. The webbing is adjustable to provide a secure fit for different users. There are typically two flotation chambers, although the TSO does not specifically require them. A tube for oral inflation is attached and inflates an emergency cell which is separate from and is enclosed by, the main shell. A survivor locator light is attached towards the top portion of the preserver and is automatically activated when the vest is in contact with water.

Life Preserver (TSO-C13)



Life Vest (TSO-C72)

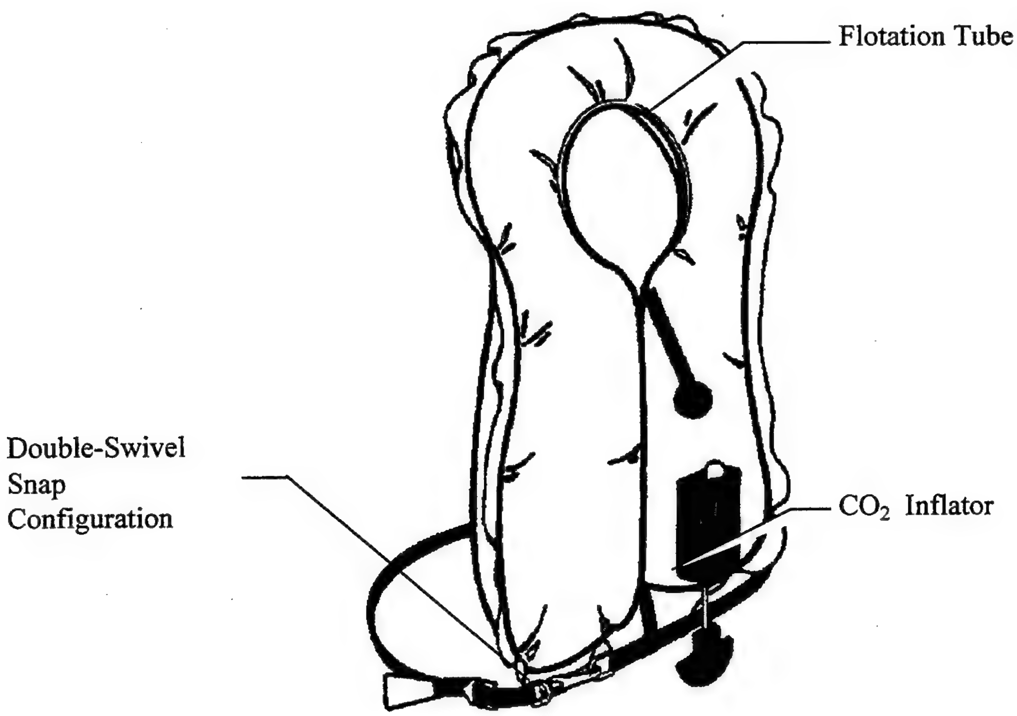


FIGURE 10. TYPICAL C-13 LIFE PRESERVER AND A C-72 LIFE VEST

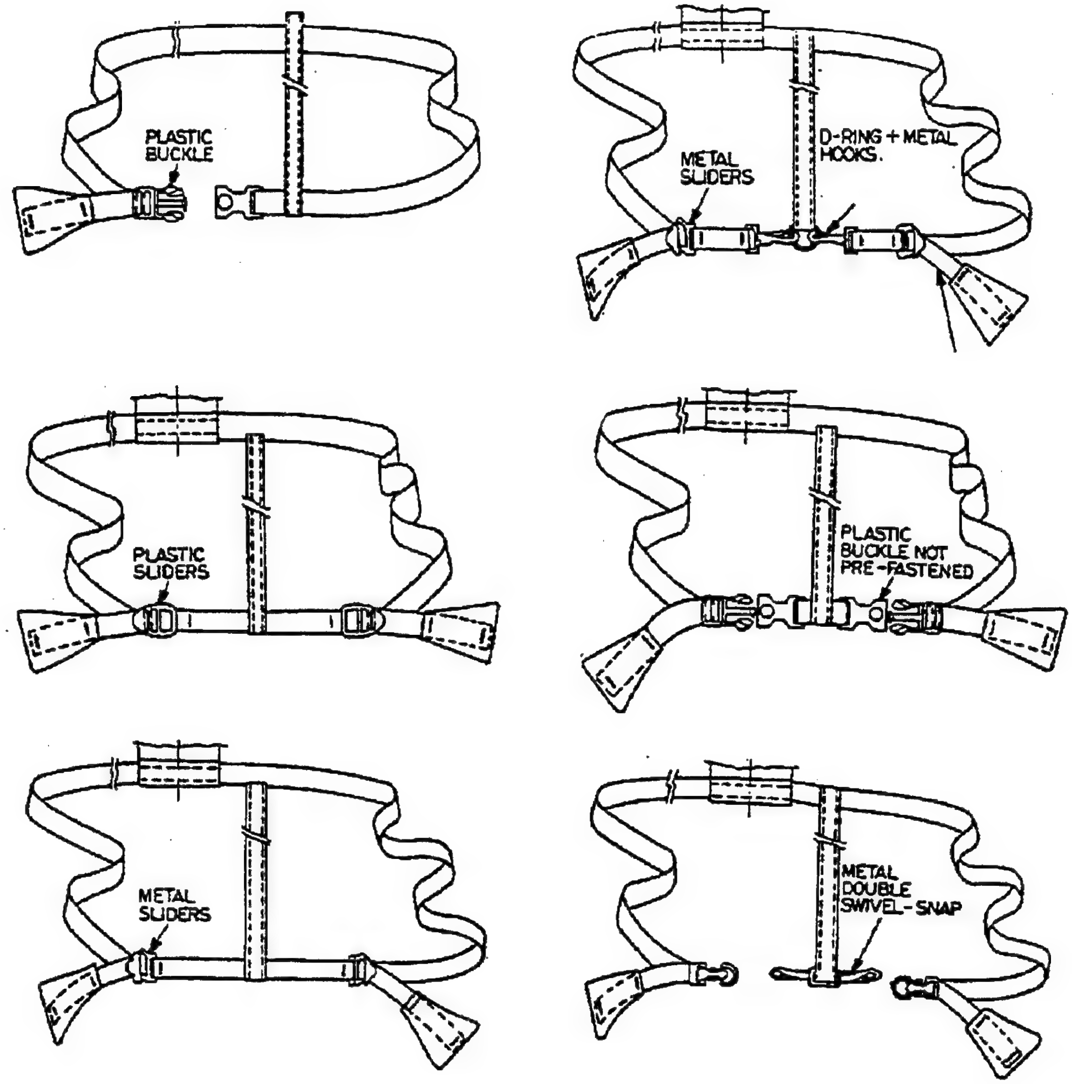


FIGURE 11. VARIETY OF FASTENING CONFIGURATIONS FOR LIFE PRESERVERS

The buoyancy performance of the life preserver depends on the category of the preserver. Adult and adult-child preservers must provide a minimum buoyancy of 35 lb. and can go up to 38 lb. The smaller child preservers provide 25 lb. of buoyancy, and infant preservers range from the required minimum of 14 to 40 lb. of buoyancy in the case of one manufacturer. This manufacturer's new infant life preserver design is among the few recent innovative advances in life preserver technology. It consists of a conical capsule in which the infant is totally shielded from contact with water and insulated to reduce the risk of hypothermia. A towing bridle and rescue handle are included to facilitate rescue.

Self-righting capability is an important feature in all C-13 life preservers. The flotation tubes bias the weight of the vest in such a way that it tends to float in an orientation where the user is positioned with his or her head well above the water line and inclined at a 45-degree angle. This is considered by experts as the ideal floating position.

Table 34 in the next section summarizes the essential features of a typical C-13 life vest.

Type-II TSO C-72 preservers are basically flotation seat cushions. These are equipped with two straps on one surface that can be used by the survivors to hold the cushion onto their chests.

Operation. To use the vest it must be removed from its storage location, the packaging removed, and the vest donned. The storage location and the type of packing have often been a source of problems in emergencies [1]; these issues are discussed further in a later section. After the vest is placed over the upper torso, the webbing is fastened, followed by a tug to tighten the fit. Most vests are not reversible; the scalloped neck and the location of the webbing help ensure that the vest is donned correctly.

The vests are equipped with CO_2 cartridges designed according to military specification MIL-C-601G. The cartridges can be internal or external to the shell body and are activated by manually pulling on the inflation handles. This is in contrast to life preservers used in military applications [10] where inflation is automatically triggered water contact. This inflation system is not employed in commercial aviation due to the danger of inadvertent or untimely inflation of the device. For example, in a flooding cabin, inadvertent inflation of the vest could cause problems in subsequent efforts to evacuate the aircraft. Inflation time for TSO C-13 vests is typically two seconds.

The TSO requires that vests be donned in 25 seconds starting with the vest in its storage location. Some preservers used in general aviation (FAR Part 91) are packaged in a pocket that is attached to a waist belt. The users first put on the belt, then open the pocket, pull the vest over their heads, and the vests are ready to use. This configuration may be faster to don but is not approved for commercial aviation because the means of donning is not obvious and may require detailed knowledge on part of the user to be effective.

Stowage. The most common storage area for life vests is below each passenger seat. The vests are stored in 5-mil-thick fire resistant packaging. A typical vest package dimension is 8 x 6 1/2 x 2 1/2 inches and it is placed in a pouch under the seat. Some newer aircraft such as the Boeing 777 and the Boeing 767 have redesigned overhead compartments to include storage of the life preservers. This is proprietary technology, however, and little information on the details of the overhead storage configuration is available. Civil Aeromedical Institute (CAMI) has also conducted studies on alternate stowage of the life preservers in the seat back. No conclusive results have been obtained to indicate this as a preferred location for life vest stowage.

Maintenance. Continued compliance with FARs and TSO certification requires scheduled maintenance and testing of life preservers. Since specific requirements are not stated

in either the FARs or the TSO, these schedules varied from manufacturer to manufacturer and from airline to airline. One manufacturer/airline combination inspected and maintained all life preservers every two years. At the other extreme, one airline did no regular maintenance for five years, then the life preservers were discarded and brand new ones installed.

LIFE RAFTS. The use of rafts is declining, especially on wide-body aircraft. Airlines are complying with raft requirements by installing combination slide/rafts. Some of the older aircraft still carry rafts or a combination of rafts and slide/rafts. Most narrow-body aircraft, however, still carry rafts.

Life rafts can be type-I (for transport aircraft) or of type-II (nontransport aircraft). Only type-I rafts were considered for this study. Figure 12 shows a schematic of a 46-person raft. A top view and a side view with the canopy inflated is shown, along with some of the required auxiliary equipment.

Features. The most common sizes of rafts carried on transport aircraft are the 25- and 46-person rafts. TSO approved type-I rafts of four- to 10-person capacity are also available. These are scaled down versions of the larger rafts, and no significant differences are seen between the various sizes.

Two flotation chambers are required for redundancy as seen in figure 12. The layout of the raft is octagonal, although circular and rectangular oval shapes are also available. The floor is a single layer; an insulated double-layer floor is available as an option.

A canopy is required for protection from the elements. Figure 12 shows a canopy supported by a number of canopy rods located at the perimeter and a centrally located canopy mast. Two types of canopy erection methods are available; manual or self-erecting (automatic). The erection times can be substantially different. This topic is discussed later in the recommendations section.

Ballast bags are located below the raft floor in figure 12. These are used to stabilize the raft in choppy water and strong winds. The ballasts fill up with water during use and lower the rafts center of gravity, thereby reducing its tendency to capsize. The deeper in the water the ballasts are located, the more effective they are.

Table 33 shows a comparison of the key dimensions and features of three sizes of rafts. The data are for typical rafts and vary from manufacturer to manufacturer.

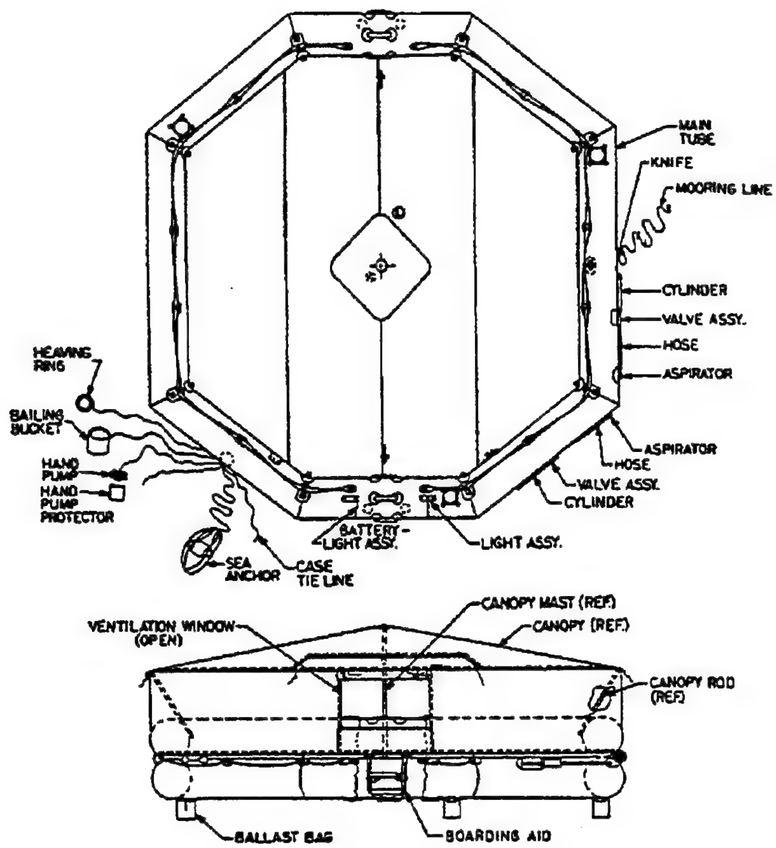


FIGURE 12. SCHEMATIC OF 46-PERSON LIFE RAFT. TOP AND SIDE VIEW (WITH CANOPY) SHOWN

TABLE 33. COMPARISON OF 46-, 25-, AND 10-PERSON RAFTS

Item	Raft Size		
	46 Person	25 Person	10 Person
Rated/Overload Capacity	46/69	25/37	10/15
Package Size (in.)	10x18x37	7x18x35	9x18x32
Package Weight (lb.)	97	63	59
Raft Diameter (in.)	202	150	103
Tube Diameter (in.)	16	13.5	12.6
Total Tube Volume (cu. ft)	146.3	76.1	40.2
Deck Area (sq. ft)	166	90.2	36
Total Buoyancy (lb.)	9136	4750	2504
Deck Area Per Person (sq. ft)	3.61	3.61	3.61
Inflation System	Air Aspirated	Air Aspirated/ Closed CO_2	Closed CO_2
Inflation Time (sec.)	12	9	-

Figure 12 also shows some of the functional equipment required per the TSO. This includes the TSO C-85 approved survivor locator lights and boarding handles for boarding the raft. Three types of lines are also required. The mooring line is tied to the aircraft when the raft is first deployed. A knife is located adjacent to it so that the line can be cut in case the aircraft begins to sink. Some slide/rafts have an alternative means of releasing the mooring line by releasing a knot tied to a D-ring. This eliminates the need for the rescue knife and is the preferred method.

A lifeline can also be seen around the outside perimeter of the raft (seen in side view). This can be used by survivors in the water for emergency flotation. A grasp line is located inside the raft (seen in top view) to support occupants. A heaving line which is used for tying rafts together or for towing the rafts is also seen. A bailing bucket is attached to remove excess water from the raft.

Many other raft accessories are required by FAR part 121 and 135. The accessory requirements are listed in appendix G.

Table 35 summarizes the key features of a TSO C-70 life raft.

<u>Operation</u>. The raft, when first deployed, is required to be attached to the aircraft by means of the mooring line. The location of attachment is near the exit doors and is typically a D-ring hook; the location of which is known to crew members. The raft is then thrown overboard in its packaging as provided. The mooring line also acts as the inflation line. The weight of the raft pulling on the mooring line releases the inflation valve and the raft inflates to full size within 9 to 12 seconds depending upon its size.

As shown in table 33, inflation can be achieved through two different methods. Larger rafts are typically air aspirated, and small rafts are inflated by pressurized CO_2 bottles. Medium size rafts can be inflated by either or a combination of the two techniques.

<u>Stowage</u>. Rafts are stored in their packaging in ceiling compartments situated above overhead baggage compartments. The compartments are situated close to exit doors. The number and configuration of life rafts varies from aircraft to aircraft and operator to operator. Some aircraft like the Boeing 767 stretch version have provisions for raft storage in the galley area. This is a more convenient and readily accessible stowage than the overhead compartments.

A typical raft packaging of a 25-person raft is shown in figure 13. The packaging also shows the flap used to cover the inflation line as required by the TSO. The valise can also be seen as a ladder-like device on the side of the raft package. As the raft inflates, the valise breaks and allows for expansion of the raft body.

<u>SUMMARY</u>. Tables 34 and 35 list the typical features of commercially available, TSO-approved life preservers and life rafts, respectively.

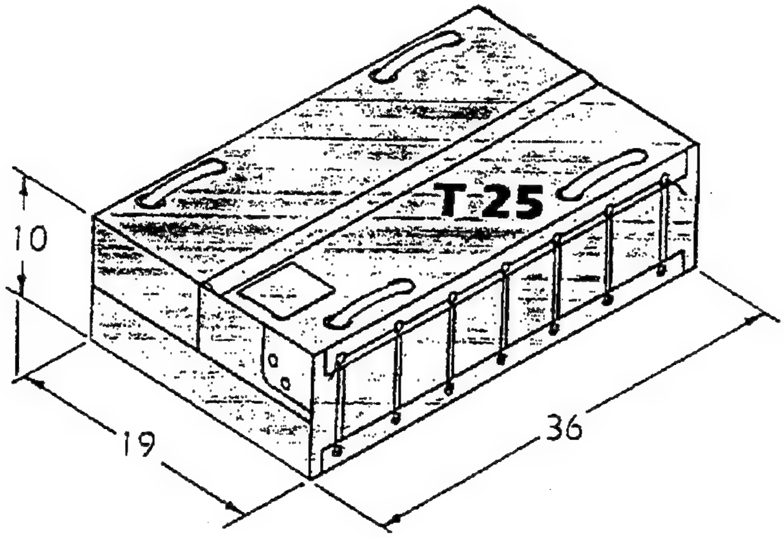


FIGURE 13. SCHEMATIC OF PACKAGED 25-PERSON LIFE RAFT

TABLE 34. TYPICAL FEATURES OF A TYPE-I ADULT LIFE PRESERVER CERTIFIED UNDER TSO C-13

Materials	Shell	Flame resistant urethane coated nylon
	Webbing	3/4-inch woven nylon/polypropylene, mildew resistant
	Fittings	Corrosion resistant metal, plastic
	Packaging	Flame resistant poly bag
Physical Features	Shape	Yoke type, fitting around wearer's neck
	Size	8 x 6 1/2 x 2 1/2 in. (packaged)
	Weight	1.5 - 2.2 lb.
	Configuration	Twin cell, containing two flotation chambers
	Construction	Heat sealed seams
	Fit	For chest sizes up to 59 in., waist size up to 54 in.
Functional Features	Oral Inflation	Available for each chamber in case of failure of compressed gas
	Locator Light	C-85 approved, automatically activated, located near shoulder of vest
	Color	International rescue bright yellow
Performance	Inflation Time	2 seconds
	Buoyancy	35-38 lb.
	Self-Righting	Self-rights wearer in less than 5 seconds
	Temperature	-40 to +140°F operating range.
Inflation	Source	CO_2 cylinders: Two 16 gram (MIL-C-601) or one 35 gram (MIL-C-25369)
Donning	Configuration	Variety available, see figure 11
	Time	Less than 25 seconds
Options		Police whistle, mirror, sea dye marker, personal ELT

TABLE 35. TYPICAL FEATURES OF TYPE-I LIFE RAFTS CERTIFIED UNDER TSO C-70

Materials	Buoyancy Tubes	Heavy duty, neoprene coated nylon
	Floor	Coated nylon
	Canopy	Coated nylon
	Webbing, Lines	Woven nylon
	Fittings	Corrosion resistant metal or plastic
	Packaging	Vinyl coated or aluminized urethane valise
Physical Features	Shape	Round, hexagonal, or square
	Size	See table 33
	Weight	See table 33
	Configuration	Two buoyancy tubes, single or double-layer floor, manual or automatic canopy
	Construction	Lap seam and tape
	Capacity	10, 25, or 46 person
	Seating Area	Minimum 2.4 $ft.^2$ per person (overload) to 3.6 $ft.^2$ per person (rated)
Functional Features	Canopy	Automatic self-erecting or manual
	Locator Lights	C-85 approved, automatically activated, placed for visibility from all sides
	Lines	Lifeline/graspline: for occupant support inside and outside raft
		Mooring/ditching: for attaching to floating aircraft
		Heaving/trailing: for attaching rafts together or towing
	Hand Pump	Bellow construction used for emergency inflation and topping up
	Reflective Tape	Metallized mylar for radar reflection and improved visibility
	Boarding Aids	Ladder and handles
	Color	International rescue bright yellow
Performance	Inflation Time	9 - 15 seconds
	Buoyancy	Depends on raft capacity, based on average occupant weight of 170 lb.
	Capsize Resistance	Water ballasts provide stability and balance
	Freeboard	Minimum 12 in. at rated occupant capacity and pressure
	Temperature	-40 to +160°F operating range.

TABLE 35. TYPICAL FEATURES OF TYPE-I LIFE RAFTS CERTIFIED UNDER TSO C-70 (Continued)

Inflation	Source	Automatic CO_2/N_2 compressed gas discharge or air aspirated
	Configuration	Independent source for each flotation tube
	Backup	Hand pump with at least 32 in.^{3} displacement per stroke
Accessories	SAR Devices	Sea dye marker, flares, flashlight, signal mirrors, marine whistles
	Signaling	ELT or Emergency Position Indication Radio Beacon (EPIRB)
	Survival Equipment	Food and water rations, reverse osmosis water maker
	Kits	First aid, raft repair, fishing
	Miscellaneous	Paddles, bailing bucket, compass, survival manual
Options		Thermally insulating double-wall floor
		Self-erecting canopy

OVERVIEW AND DISCUSSION.

This section addresses recommendations pertaining to the design, performance, and regulatory requirements of the flotation devices in this study. The recommendations arise from a variety of sources including a comparative review of vendor information, NTSB recommendations [3], CAMI studies [11, 12], and phase-I of the Transport Water Impact study [1] as well as current regulations.

LIFE PRESERVERS AND PFDS. Life preservers in the majority of the cases meet the minimum requirements of the TSO. In recent years, the only industry changes in life preserver design have been in improving wearability and comfort. Any design changes are checked to ensure the minimum performance requirements are met. Hence, performance features and design improvements have historically tracked with the evolution of the TSOs which in turn have been periodically refined, primarily due to NTSB recommendations. The following is a list of recommendations:

- PFD Design. The performance and effectiveness of flotation seat cushions have always been debated. The PFDs most commonly used are flotation seat cushions and single-cell life vests described in TSO C-72. They provide about 14 lb. of buoyancy, which experts contend is barely enough to adequately support an adult. A CAMI study in 1966 recommended that flotation seat cushions be held against the chest in one of two techniques. An NTSB study [3] later said that it is unlikely that every crash victim is a conscious, viable adult, capable of attending to his or her flotation needs. Hence, the Board recommendation A-84-02 suggested that the FAA "require the installation of TSO C-13d life preservers on all part 121 air carrier aircraft."

Nevertheless, the NTSB believes that flotation seat cushions should also be on every aircraft. In an unplanned impact, as is most often the case, there may not be an opportunity to locate and don life preservers. In such cases, randomly floating seat cushions may be the only readily available means of flotation.

Another study by CAMI [11] recognized that the "diligent personal attention from the onset of crisis till rescue" is required by victims while using flotation seat cushions. The study suggested several methods to use flotation cushions more effectively to provide flotation as well as hypothermia protection. These methods, however, require interaction between multiple survivors and more importantly training or some prior knowledge of these techniques for them to be effective.

- Stowage. Stowage locations of the life vests have been a major cause of concern for the NTSB. The stowage location has predominantly been under the seat. There have been several situations where this location has caused retrieval problems; examples being the 1970 crash of Overseas National Airlines near St. Croix, the Eastern Airlines ditching offshore in Miami in 1983, and the SAS accident at JFK Airport in 1984. Passengers were not able to reach under their seats, preservers were ejected from their stowage and inaccessible due to rising water, postimpact seat collapse and the presence of excessive or over-sized baggage in the cabin caused additional problems.

  One possible solution to most of these problems is to consider the overhead stowage location previously mentioned in this section. Detailed trials under simulated crash conditions are required to confirm the usefulness of this recommendation. Reference 3 generalized this recommendation by requiring the regulations to preclude stowage in locations vulnerable to water impact damage to the fuselage, seat collapse, or cabin flooding. Also, to the extent possible, the location should be standardized across various cabin designs in all aircraft.

  Another recommendation is to amend the testing regulations to require timed retrieval and donning tests to start with the life preserver in the package and in its stowage location rather than in the user's hand.

- Packaging. Life preserver packaging has caused problems in almost all the known water impacts. Instances have been recorded where crew members had to use their teeth to chew on and tear the packaging to remove it, or passengers had to use tools such as a pocket knife. These problems are easily exacerbated by conditions such as low lighting and cold weather. Packaging designs should be reconsidered in light of these experiences.

- Donning. Reports from past accidents indicate passengers were confused about the exact donning procedure even though preflight demonstrations addressed donning. The fact that typically many passengers do not pay attention to preflight donning instructions could be an explanation for users often getting entangled in the webbing.

The NTSB study[3] noted that the only way to remove these serious deficiencies is to impose much more severe testing requirements in order to gain certification. This is required to balance the much more severe conditions in a real emergency, compared to the relatively benign environment in which donning tests are done. Since it is difficult to emulate the physical and mental status of victims in an emergency, alternative means of increasing testing severity need to be devised. One such suggestion by the NTSB was to not provide donning instructions prior to testing for TSO approval.

- Vest Design. A certain amount of confusion among passengers exists in the terminology used to describe flotation devices as "vests." Many passengers expect to see a vest similar to an "angler's vest" design that needs to be donned much like a shirt. Studies done by CAMI [11] have proven that angler style vests can be donned much faster than life preservers. Average donning times were between 16 and 17 seconds for anglers vests and 21 to 37 seconds for conventional life preservers. Angler's vests (noninflatable types) made of closed foam material offer the added reliability advantage in that there are no inflation cylinders and related release mechanisms or any moving parts. This dramatically reduces the chance of failure. Furthermore, they are more likely to offer a higher level of protection from hypothermia than life preservers, simply because of the fact that they wear tightly on a large surface of the user's body.

One obvious problem with angler's vests, especially of closed foam design, is that they would be typically bulkier than an uninflated life preserver. The buoyancy provided per cubic inch of foam systems is also lower than inflatables. Another problem is that angler's vests have to be designed for the general population encompassing a large range anthropometric characteristics. A prototype vest developed by CAMI addressed this problem by employing sliding panels.

Two other recommendations arise from reference 13. A comparative study including wet trials of life vests obtained from various manufacturers was done. One of the design enhancements mentioned was to replace the standard pull handles (used for automatic inflation) in the traditional hook style double finger design with a handle consisting of a series of plastic balls. This design reduces the chance of the pull mechanism getting accidentally caught on something. Another recommendation was the inclusion of a neck gusset or liner on the neck area of the vest to improve wearer comfort and reduce chaffing, which was evident in some of the drill participants.

- Search and Rescue. Approved survivor locator lights should be required on all life vests including TSO 72 certified vests. There is no evidence to suggest that these vests would only be required in better light conditions. In addition, a cost-effective and simple modification would be to add retroreflective tape and radar reflective strips on the top surface of the vests to aid in SAR. Radar reflective panels made of metalicized mylar are currently used as an option on some life rafts. Another simple design feature would be to incorporate harnesses to allow for persons to be extricated from the water with ease.

- Infant Life Preservers. Young children and infants are very susceptible to hypothermia; hence this is an added consideration in infant life preserver design. A new product available today addresses the problem by providing a totally enclosed survival capsule. Ventilation is provided by a system of specialized ports that also serve to prevent entrance of water. Reference 13 also recommends the addition of radar reflective tape in addition to the retroreflective tape already on the vests. This would provide additional help for SAR efforts.

- Quantities of Infant Life Vests. Currently there are no data on the number of infant vests carried onboard. FARs should be amended to reflect the required minimum number as well as approved stowage locations of infant life vests.

- Hypothermia Protection. A prototype modified life preserver was developed by CAMI [12] which addresses the problem of the current "open back" design which offers very little protection from hypothermia. The prototype has a closed foam neoprene back and extended frontal coverage of the chest and abdomen area by stretching the frontal vest material to cover those areas. Incentives to make this technology more affordable may bring these features to life vests carried on all aircraft.

- Crew Training. It was observed [3] through several water accidents that higher levels of training and communication between crew members contribute to effective performance in emergencies. In reference 3, the NTSB recommended that the FAA require airlines to conduct periodic crew training in evacuation and wet ditching drills. Efforts also need to be made to improve crash survival and crew leadership.

- Public Training. The lack of preparedness on the part of passengers forms the greatest hazard to safety as concluded by one cabin safety expert in reference 14. The value of knowledgeable, mentally prepared passengers was readily observed in the ditching of an Overseas National Airways (NTSB AAS 72-2) DC-9. Just as the Red Cross certifies members of public for first aid and CPR, it is conceivable to train a section of the public on the use of flotation equipment and aircraft exits. This would certify them as such, and they can be seated at seats located near exits. This would essentially multiply the emergency crew available for assisting other passengers by a factor of two or three.

<u>LIFE RAFTS</u>. Recent trends indicate that airlines are moving away from the use of life rafts towards reliance on slide/raft combinations on wide-body aircraft. However, narrow- and medium-body jets still rely on life rafts or a combination of slide/rafts and life rafts. This move towards slide/raft combinations may be welcome as evident from the comments regarding life rafts in reference 3 citing an FAA study stating that life rafts "are of questionable value under any condition, but particularly in the inadvertent case where preparation time is nonexistent and immediate fuselage rupture and flooding is probable." In addition, the study points out that in such conditions "the probability of anyone remaining behind to retrieve and deploy this equipment...is virtually zero."

Reference 2 cited 11 water impacts occurring between 1959-1979. Of these, only four occurred in deep water where life rafts were required. Life rafts were used in only one of these accidents. The lack of empirical data on the performance of life rafts makes it difficult to evaluate field performance in an emergency and to make recommendations for improvements. Nevertheless, some recommendations are presented in this section. Like vests, most life raft manufacturers do not design beyond the minimum requirements of the applicable TSOs.

Stowage. Most rafts are stored in overhead compartments. There is relatively little space available in already crowded interiors for the raft packages which tend to be bulky (see table 33). It is difficult even for a few able bodied men to remove the 60-100 lb. raft from storage in ideal conditions. As the NTSB study noted, in an emergency, the opportunity to use the rafts is slim. As mentioned earlier, there are provisions on some aircraft to carry rafts in the galley. This is a preferable location in terms of ease of accessibility and retrieval.

For narrow-body aircraft where slide/raft combinations are not used, it is imperative to place the rafts in a location where they would be easily accessible and need only one person to deploy, even in adverse conditions. Further study is needed to define such an appropriate location. With lighter and thinner raft shell materials and advanced packaging techniques, rafts can be packaged into a smaller volume. It may be possible to place the raft package in locations previously unconsidered such as the wing fairing where exit ramps are sometimes stored in wide-body aircraft or within the door frame itself. An added advantage of these locations is that the users need not remember to tie the mooring line to the aircraft before launching the rafts, as they could be pre-moored. This can be an important advantage in an emergency.

Raft Shapes. A study in reference 15 field tested life rafts from a number of manufacturers. It was observed that for stability in rough water, round or almost round (hexagonal, octagonal) rafts are far superior to square or rectangular rafts. Based on Coast Guard studies and advice of raft designers and safety instructors, a square raft is likely to settle in a wave trough and capsize; whereas round rafts are more likely to carousel rather than capsize. Raft shapes are not mandated in current regulations.

Canopy Erection. Both self-erecting and manual canopies were tested in reference 15. The tests indicated that self-erecting canopies were up in a few minutes at most. In contrast, subjects had a tough time locating parts required for manual canopy erection, and erection times varied from 14 to 33 minutes to a team that became frustrated and gave up. Considering the immense importance of the protection these canopies afford [15], it would seem prudent to require self-erecting canopies on all rafts.

Valise Covering. The valise is a ladder-like configuration of nylon string used to hold the raft in its package (figure 33). It is designed so that as the inflation line is pulled, the inflation force of the raft causes the valise to break and allow the raft to inflate to full size. It was observed in reference 15 that subjects tended to undo the valises to try to inflate the raft instead of simply pulling on the inflation lanyard. Although this does not render the raft useless, in an emergency, precious time may be lost in performing this needless task. Valises should be

required to be covered in a way so as to make it perfectly clear to the user the proper means of inflating and deploying the raft.

Sea Anchors. Sea anchors are essential to the stability of the raft. They act as drag inducing devices which trail behind the raft and help maintain its position in relation to the waves and prevent excessive rotation. The study indicated that sea anchors were often torn away in moderate to heavy seas when it was needed the most. The strengths of lines and fittings securing sea anchors to the raft need to be studied.

Lifelines. Lifelines are required to help survivors in the water to hold on to the raft. Often, the location of the line was too high on the raft tube, or it was difficult for subjects in the water to see them. Hence the study recommended that lifelines be brightly colored for better visibility, and the webbing style should be such that it alternates from top of the tube to the bottom in a crossing pattern.

Raft Floor. A wet drill, organized by Florida Public Safety officials and several airlines [16, 17]), was recently conducted in Florida. One of the drills involved subjects in different rafts in simulated crash conditions. Even though the waters of the Atlantic Ocean were at a temperature of 78°F during the test, a 10-hour overnight stay in the rafts showed that survivors in double-floor insulated rafts faired much better than those in rafts with single layered floors. Double-floor insulation is a simple feature that could easily be incorporated on all new rafts.

Materials Used. One manufacturer minimizes the use of metals to reduce metal to nylon chaffing and minimize the chance of puncture or tearing. In that design, the only place metal is used is in the pop-up valve and the relief valve used to reduce excessive pressure. This is a good design practice that could be incorporated in all designs.

Wet Tests. Life rafts are a fairly complex piece of equipment, and a real evaluation is only possible by conducting live drills involving people of different age groups, sex groups, and ability. It is here that potential shortcomings can be identified and possible design changes can be tested for implementation. It is recommended that these drills be made part of the standardized testing and certification procedures to get a realistic indication of the performance of life rafts.

CONCLUSIONS.

Section 1. Accident Data Analysis:

a. The trends in the hypothetical water accidents, as indicated by the analysis results, appear to reasonably reflect those trends found in the water accident data reviewed for this study. The ditching accidents showed a greater percentage of fatalities, from both impact and postimpact causes, than did the overrun accidents.

b. When the outcomes of the hypothetical water impact accidents are compared to those of the land accidents on which they were based, the trends again seem reasonable. Greater numbers of impact fatalities occurred in the land accidents than in the water accidents; however, the number of postimpact fatalities was greater in the hypothetical water accidents.

c. The hypothetical water impact model illustrates the interdependencies of the key factors that affect occupant survival. The model was not intended to predict exact numbers in these hypothetical cases, but to attempt to capture the relative importance of various factors on occupant survivability in such scenarios. There is room for further refinement and sophistication of the tool.

d. The model provides a means to investigate "what if" cases to determine the sensitivity of the predicted outcomes to various parameters, such as aircraft impact damage and flotation equipment performance. Exercise of the model indicated that the results were very sensitive to the aircraft damage parameter.

Section 2. Airport Water Rescue:

a. At present there are no regulations that require airports to operate and maintain facilities, equipment, or personnel focused on water rescue situations.

b. Unlike fire-fighting operations on airports, no standardized requirements exist for the number, quantity, or type of water rescue vessels, water rescue equipment, or the number or training level of water rescue personnel.

c. Although mutual-aid agencies can be an important part of an airport water rescue plan, such agencies may not be able to provide prompt response to water rescue emergencies.

d. Larger airports are more likely to have on-site water rescue capabilities. Among airports surveyed, 75 percent of large, 43 percent of medium, and 25 percent of small airports had some level of on-site water rescue capability.

e. Airports with immediately adjacent water bodies are more likely to have water rescue capabilities than airports with water bodies within five miles of airport property. Sixty percent of the airports in the survey that are situated adjacent to a body of water had on-

site water rescue capabilities, in comparison to only 22 percent type W airports situated within five miles of a significant body of water. Thirty-eight percent of airports located immediately adjacent to water had no water rescue capability whatsoever.

f. Different types of water bodies have different water rescue requirements. The type of water rescue vessels and equipment and the training of water rescue personnel should be based on several factors typical to the airport's water environment, including the type of water body and the temperature and depth of the water body.

g. The number, type, and capabilities of water rescue vessels in the fleet, water rescue equipment, and personnel training may vary greatly form airport to airport.

h. The most extensive water rescue plans among surveyed airports exist at San Francisco International, Boston-Logan International, Washington National, and Portland International. It should be noted that three of these airports have been the sites of major transport aircraft water accidents.

i. Airports that have provisions to keep rescue vessels docked in the water have a dramatically lower average response time (3.6 versus 8.4 minutes) than airports that do not have such provisions.

j. Water rescue training should cover, at a minimum, the eleven topics identified in the subparagraph Personnel on page 39.

k. Only 42 percent of type N airports surveyed maintained a support inventory identifying the mutual-aid agencies for water rescue and their water rescue emergency response plan. Support inventories identifying mutual-aid agencies are not always maintained at airports that rely predominantly on such agencies for water rescue capability.

Section 3. Emergency Flotation Devices:

a. The threat of hypothermia due to water immersion is a major concern in aircraft water impact. Emergency flotation devices are essential to reducing the threat of hypothermia.

b. A survey of flotation devices found that the devices are designed to meet the minimum requirements for TSO approval. No real additional advanced features or performance characteristics are incorporated above and beyond the TSO specifications.

c. Advanced infant life preservers that incorporate hypothermia protection are currently available. These preservers use an advance thermal capsule design.

d. Although the performance of flotation seat cushions has been debated, it is still recommended that they be included on all aircraft. In unplanned water accidents, they are likely to be the only available means of flotation.

e. Using TSO C13 life preservers in place of the comparatively inferior TSO C-72 was recommended. Improved design incorporating increased protection from hypothermia was also recommended.

f. The stowage location, retrievability, ease of unpacking and donning still remain the main factors in the effectiveness of inflatable PFDs and life preservers.

g. Basic regulatory amendments to improve field testing and demonstration of PFDs were suggested.

h. Review of flotation equipment indicates that raft stability, canopy design, packaging valise, and stowage location may be improved.

REFERENCES.

1. Patel, Amit A., Richard P. Greenwood, Jr., "Transport Water Impact and Ditching Performance," DOT/FAA/AR-95/54.

2. Johnson, Richard, "Study on Transport Airplane Unplanned Water Contact," DOT/FAA/CT/84-3, February 1988.

3. National Transportation Safety Board, "Safety Study—Air Carrier Over-Water Emergency Equipment and Procedures," NTSB/SS-85/02, June 12, 1985.

4. Department of Transportation, Federal Aviation Administration, "Commercial Jet Transport Crashworthiness," Boeing Commercial Airplane Company, March 1982, DOT/FAA/CT-82/68.

5. Department of Transportation, Federal Aviation Administration, "Transport Aircraft Accident Dynamics," McDonnell Douglas Corporation, March 1982, DOT/FAA/CT-82/70.

6. Department of Transportation, Federal Aviation Administration, "Transport Aircraft Crash Dynamics," Lockheed-California Company, March 1982, DOT/FAA/CT-82/69.

7. Advisory Circular 150-5210-13A—Airport Water Rescue Plans, Facilities and Equipment.

8. National Transportation Safety Board, "Airport Certification and Operations," NTSB/SS-84/01, April 11, 1984.

9. National Transportation Safety Board, "Aircraft Accident Report—World Airways Inc., Flight 30H," McDonnell Douglas, DC-10-30CH, N113WA, Boston-Logan International Airport, Boston, Massachusetts, January 23, 1982," NTSB/AAR-85/06.

10. Air Standardization and Coordinating Committee AIR STD 61/4, "Flotation and Sea Survival, Test Methods and Requirements," 5 September 1975.

11. Funkhouser, Gordon E., Mark H. George, " Alternative Methods for Flotation Seat Cushion Use," DOT/FAA/AM-95/20, May 1995.

12. Rueschoff, B.J., E.A. Higgins, M.J. Burr, and D.M. Branson, "Development and Evaluation of a Prototype Life Preserver," DOT/FAA/AM-85-11, September 1985.

13. Ritter, Douglas S., "Staying Afloat," Aviation Consumer, Vol. 24, No. 12, 1994.

14. Edwards, Mary, "Safety In The Air—What More Can Be Done," Cabin Crew Safety, Flight Safety Foundation, Vol. 26, No. 3, 1991.

15. Ritter, Douglas S., "Life Rafts," Aviation Consumer, Vol. 24, No. 7, 1994.

16. Wiggins, Shawni, "Surviving 15 Hours Adrift in the Atlantic," The Tampa Tribune, December 17, 1994.

17. Wiggins, Shawni, "Disaster Drill—In Their Largest Ever Exercise, Airlines Will Test Rescue in the Ocean," The Tampa Tribune, December 3, 1994.

APPENDIX A—WATER IMPACT MODEL

This appendix describes the steps used for predicting the water impact outcome for the land accidents listed in table 1.

1. Assign Damage Factor.

- Use figure 4 for ditchings
- Use figure 5 for overruns

2. Calculate Time Afloat.

Time afloat is found from

$$t_a = d/4 \times t_b$$

where t_a = Time afloat

t_b = Baseline flotation time
d = Damage factor from step 1

The baseline time afloat is proportional to the weight-to-volume ratio (density) of a particular aircraft. It is found from

$$\frac{\rho_b}{\rho_r} = \frac{t_r}{t_b}$$

$$t_b = \frac{\rho_r}{\rho_b} \times t_r$$

$$t_b = \frac{\left[\dfrac{W}{V}\right]_r}{\left[\dfrac{W}{V}\right]_b} \times t_r$$

Where the symbols used are

t_r = Known flotation time of reference DC-7C (case 11, table 1)
ρ_r = Known density of reference DC-7C (case 11, table 1)
ρ_b = Baseline density of aircraft
W = Weight of aircraft at time of accident
V = Volume of aircraft, estimate of fuselage volume cylinder + unit volume of wings

3. Calculate evacuation time.

The required evacuation time is calculated from

$$t_e = t_{b,e} \times \{(PAX_{total} - PAX_{fatal}) / E_a\} \times F_a \times F_b \times F_c \times F_d \times F_e + 0.75$$

where the symbols represent the following

t_e = required evacuation time.

$1/t_{b,e}$ = baseline evacuation rate.

It is based on the maximum number of occupants for a given aircraft model divided by the maximum number of exits and a time of 90 seconds.

PAX_{total} = Total number of passengers on board

PAX_{fatal} = Total number of impact fatalities.

It is based on statistical average of known water impact occurrences.

E_a = number of available exits.

Equal to the maximum number of exits minus the number of failed exits (i.e., damaged, obstructed). The number of failed exits is found as the average number of exits that failed in the known water impacts adjusted to account for the damage impact factor assigned for the particular land accident.

Number of failed exits = {Average Failures + (0.7-d)/10} $\times$ total exits

The average exit failures were calculated to be 22% for overruns and 17.5% for ditchings.

F_a = Preparation factor

Used to account for level of planning prior to accident. The value is 1 if prepared; 1.3 if unprepared.

F_b = Crew effectiveness factor effectiveness in assisting passengers in evacuating.

It is 1 if effective; 1.2 if ineffective

F_c = Impact injury factor

Estimated as a function of passengers with serious injuries, minor injuries, and no injuries.

It is calculated from the following equation.

$$F_c = (1.5 \times \text{PAX seriously injured} + 1.2 \times \text{PAX with minor injuries} + 1.1 \times \text{PAX uninjured}) / (\text{Total PAX that survived impact})$$

F_d = Illumination factor

It depends if accident occurred in daylight or nighttime conditions. It is 1 if daytime; 1.15 if nighttime.

F_e = Cabin damage and obstruction factor.

It is based on the impact damage factor d as

$$F_e = 1 - (1 - d)$$

A constant time of 0.75 minutes (45 seconds) is added to evacuation time to account for delay in beginning evacuation due to shock, trauma, or other factors that may be expected to contribute towards a delayed initiation of the emergency evacuation.

4. Calculate postevacuation survivors.

The number of postevacuation survivors is calculated from the following equation. Note that the symbol # is used to abbreviate for "number of" in the following section.

survivors = {# evacuees in rafts}+{ # in water - # drowning fatalities - # exposure fatalities}

The number of evacuees in rafts is calculated from:

evacuees in rafts = { # rafts available × raft capacity}

Raft capacity was used as 25 for narrow-body jets, 46 for wide-body jets.

in water = {# evacuees - # evacuees in rafts}

The number of drowning fatalities is calculated in the following equation:

$$\text{\# drowning fatalities} = \text{\# water} \times \{ (D_a-1) + (D_b-1) + (D_c-1) + (D_d-1) + (D_e-1) + (D_f-1) \} \times \{1-(1-PFD_r)\}$$

Where the following symbols are used:

D_a = weather factor: 1.05 for poor weather ; 1 for good weather

D_b = preparation factor: 1.05 for well prepared; 1 for no preparation

D_c = impact Injury factor as in number of evacuees computation in step 3.

D_d = crew effectiveness factor: 1.1 ineffective; 1 if effective in directing use of flotation equipment.

D_e = rescue availability: 1.05 for ditchings assuming they typically occur far from the airport and it may take longer for SAR to take effect; 1 for overruns since they always occur in close proximity to the airport

D_f = water depth; 1.05 for deep water (typically ditchings); 1 for shallow water (typically overruns)

PFD_r = PFD reliability; typically assumed as 0.85

The number of exposure fatalities is calculated in the following equation:

exposure fatalities = {# evacuees - # drowning fatalities} × {D_g-1}

Where D_g = Water temperature factor: 1.05 if cold; 1 if mild (cold <55°F)

APPENDIX B—INDEX OF ADVISORY CIRCULARS

Advisory Circulars related to airport rescue department operations.

150/5200-31 Airport Emergency Plan
150/5210-2A Airport Emergency Medical Facilities and Services
150/5210-6C Aircraft Fire and Rescue Facilities and Extinguishing Agents
150/5210-7B Aircraft Fire and Rescue Communications
150/5210-13A Water Rescue Plans, Facilities, and Equipment
150/5210-18 Systems for Interactive Training of Airport Personnel
150/5220-10A Guide Specification for Water/Foam Aircraft Rescue and Fire-Fighting Vehicles.

APPENDIX C—EMERGENCY WATER RESCUE VEHICLES

Categories of rescue vehicles that may be used for facilitating water rescue.

1. Conventional Boats. Useful for transporting rescue personnel and equipment, deploying flotation equipment, picking up survivors, fire fighting, communications, etc. Some boats may be used as RIVs employed in conventional ARFF rescues.

2. Rescue Boats/Ships. Typically 17 to 40 ft. in length, constructed of a fiberglass or aluminum hull. These can be used for removal of a section of the hull to provide easy access to the water. Sheltered accommodations may be available for survivors.

3. Amphibious Fireboat. Capable of traveling on land and water and useful for rough terrain, steep slopes, and flooded areas as well as for permanent, significant bodies of water.

4. Flotation Platforms. Deployed by other vehicles, these devices can be used to provide temporary flotation to survivors.

5. Inflatable Boats. Typically 22 to 28 ft. long, can be jet propelled, and can be used to hold up to 15 survivors.

6. Shallow Draft Airboat. Typically 13 to 20 ft. long and driven by aircraft-like propellers. Can operate in extremely shallow water, tidal flats, marshes, and snow.

7. Air Cushion Vehicles. Can be used similar to conventional boats, but in shallow water and mud flats.

8. Helicopters. They are ideal for quick response and for deploying personnel and equipment.

APPENDIX D—AUXILIARY WATER RESCUE EQUIPMENT

Auxiliary Equipment For Water Rescue.

Survivor Equipment.

Foam vests
Inflatable vests
Toss rings
Throwable flotation bags
Flotation boards
Thermal blankets

Rescue Personnel Equipment.

Flotation vests equipped with harness, rescue knife, whistles, and lights
Face masks/eye protection (in presence of oil spills or hazardous materials in the water)
Bailing buckets
Scuba gear
Dry suits
Portable resuscitation equipment

Search Equipment.

Area maps
Navigation charts
Bull horns
Emergency lights, flares, flare guns
Sonar
Portable flood lights

Rescue/Extrication Equipment.

Rescue nets
Towing bridle
Dragging and underwater rescue equipment
Forcible entry tools
Grappling bars
Hooks, helicopter netting baskets

APPENDIX E—SAMPLE SUPPORT INVENTORY

Figure E-1 is a list "Water Rescue Resources" available at the Little Rock airport. It identifies seven mutual-aid agencies along with their contact numbers and the type and capacity of rescue vessels that may be available.

EXHIBIT VII
WATER RESCUE RESOURCES

AGENCY	CONTACT/TELEPHONE	RESOURCE	CAPACITY
Pulaski, County Sheriff (Water Patrol)	Major Bob Scarborough Telephone 9-1-1 Marine Telephone	3 Boats	10
Corps of Engineers Terry Lock & Dam Murry Lock & Dam (backup)	Wendell Gray 961-9281 Henry Hines 663-1197	River Traffic	N/A
Little Rock Harbour Services	Paul Hastings	Tug Boat	50
Port of Little Rock Terminal	Terry Sims 490-1521	2 Boats	5
U.S. Coast Guard Auxiliary	Richard Lawrence 375-5253 (day) 663-2312 (night)	5-8 Boats	5
Little Rock Power Squadron	Steve Owen 374-0353	2-10 Boats	5
Little Rock Fire Department	Chief Rubin W. Webb 371-4795	2 Water Rescue Craft	N/A

FIGURE E-1. SUPPORT INVENTORY AT LITTLE ROCK AIRPORT: WATER RESCUE RESOURCES

Figure E-2 is a flow chart indicating the flow of events from an operational standpoint in the event of an aircraft impact in the Arkansas River. The agencies to be notified and mobilized, if required, are identified.

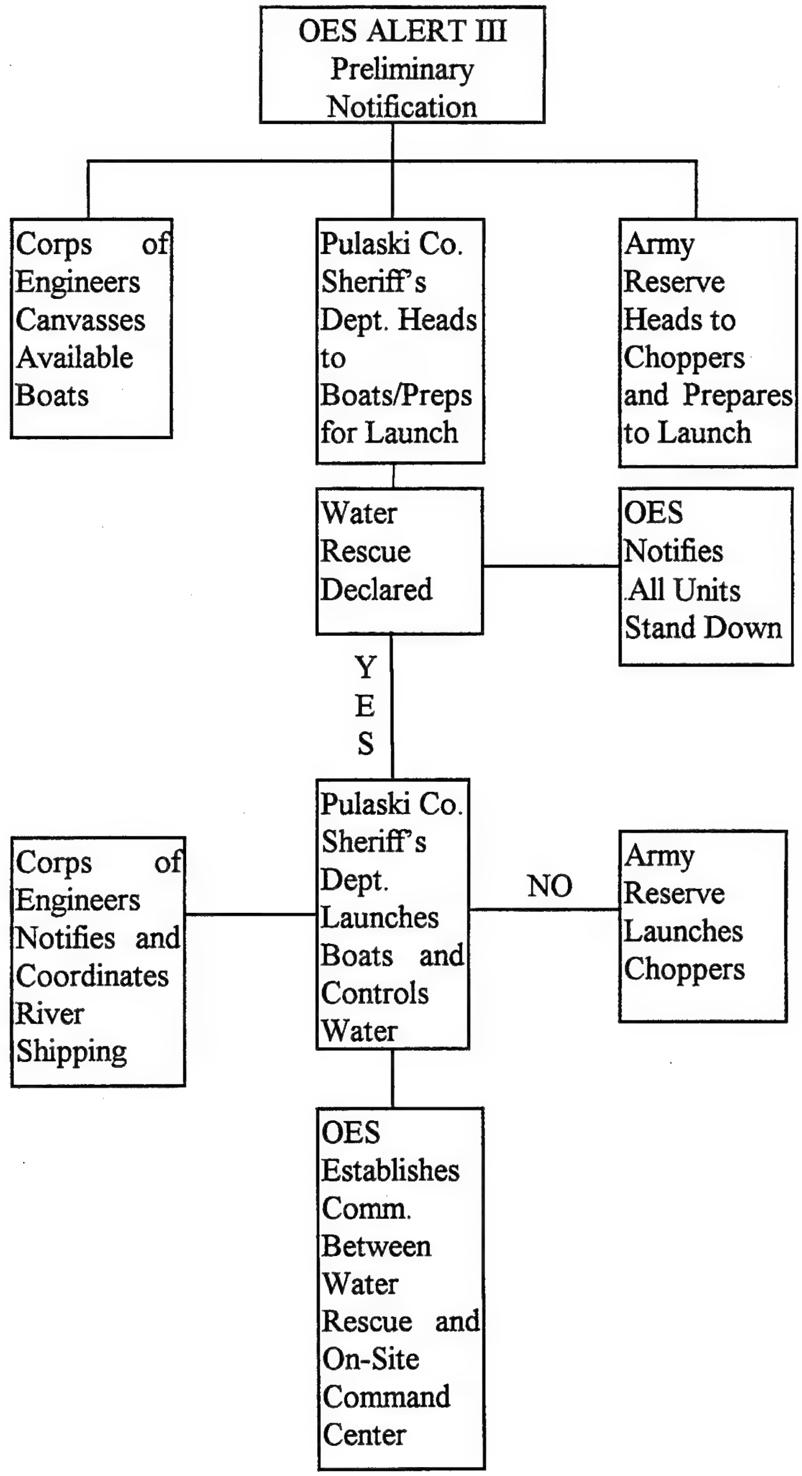


FIGURE E-2. SUPPORT INVENTORY AT LITTLE ROCK AIRPORT: OPERATIONS CHART

APPENDIX F—LIST OF FEDERAL AVIATION REGULATIONS

List of FARs and their titles referenced in this Study.

FAR	Title
FAR Part 25	
25.810	Emergency Egress Assist Means and Escape Routes
25.1411	Safety Equipment
25.1415	Ditching Equipment
FAR Part 121	
121.291	Demonstration of Emergency Evacuation Procedures Criteria for Demonstration of Emergency Evacuation Procedures
121.309	Emergency Equipment
129.310	Additional Emergency Equipment
FAR Part 125	
125.189	Demonstration of Emergency Evacuation Procedures Criteria for Demonstration of Emergency Evacuation Procedures
125.207	Emergency Equipment Requirements
	Additional Emergency Equipment
125.209	Emergency Equipment: Extended Over-Water Operations
125.337	Briefing of Passengers Before Flight
FAR Part 135	
135.167	Emergency Equipment: Extended Over-Water Operations
135.311	Crewmember Emergency Training

APPENDIX G—AUXILIARY EQUIPMENT ON LIFE RAFTS

Auxiliary equipment required on life rafts per FAR parts 135.167 and 125.209.

Raft Accessories Required Per FAR Parts 121 and 135		
Item (Quantity)	FAR Part	
	125	135
Canopy (1)	x	x[a]
Radar reflector (1)	x	x
Life raft repair kit (1)	x	x
Bailing bucket (1)	x	x
Signaling mirror (1)	x	x
Police whistle (1)	x	x
Raft knife (1)	x	x
Spare CO_2 bottle (1)	x	x
Inflation pump (1)	x	x
Oars (2)	x	x
75-ft. retaining line (1)	x	x
Magnetic compass (1)	x	x
Dye marker (1)	x	x
Flashlight (1)	x	x
Pyrotechnic signaling device (1)	x	x
Food rations (1 per occupant)	x	x
Sea water desalting kit (1)	x	x[b]
Fishing kit (1)	x	x
Survival book (1)	x	x
ELT	x	x
Survival kit	x	x[a]
Survival locator light (1)	x	x
a: Either survival kit or canopy required b: or 2 pints of water per occupant		

APPENDIX H—TECHNICAL STANDARD ORDERS C-13, C-72, AND C-85

C-13F—LIFE PRESERVER

1. Overview: Categorizes life preservers into Type-I (inflatable) and Type-II (noninflatable). Further subcategorizes each type depending on the weight of the wearer, as "Adult" (>90 lb.), "Adult-Child" (>35 lb.), "Child" (35-90 lb.), and "Infant"(<35 lb.).

2. Material requirements are separately categorized for nonmetallic and metallic parts. The only requirements for the latter is that they be corrosion resistant. Quantitative requirements in the area of tensile strength, tear strength, permeability, coat adhesion, seam tape strength, seam load, and peel test are given for coated fabric materials. In addition, tensile strength of webbing, size and strength of threading, and fungus resistance are specified for materials other than coated fabrics.

3. Detailed requirements: Below is a list of requirements/specifications.

- Reversibility—preserver must perform equally well when reversed.

- Protection—flotation chambers must be protected against abrasion and chafing from metallic components.

- Inflation/deflation—each flotation chamber must meet the following requirements:

  Oral inflation means must be provided, must be readily available, and usable without previous instruction.

  Oral inflation valve with an opening pressure of 0.6 psig. The oral inflation joint strength and size are specified.

  A gas reservoir with a suitable compressed gas for inflation by manual means.

  Pull cord assembly extending 1 1/2 to 2 inches from the bottom of the preserver. The end of the pull cord must be attached to a pull knob/tab with rounded edges.

  Deflation means allowing subsequent re-inflation.

- Functional temperature range of -40 to +140°F is required.

- Overpressure protection requires a flotation chamber to stay intact after discharge of the compressed gas, even after having been manually inflated.

- Minimum buoyant force for each category of preserver as follows

Category	*Minimum Buoyant Force*
Adult	35 lb.
Adult-Child	35 lb.
Child	25 lb.
Infant	20 lb.

- Flotation attitude—the life preserver must have the tendency to right the wearer who is in the water in a face down attitude. It must accomplish this within 5 seconds. The preserver must provide lateral and rear support to a completely relaxed wearer's head and keep it held clear of the water line.

- Infant preservers must have the following features:

  Wearer's upper torso must be kept from contact with water.

  There must be no tendency of the life preserver to capsize or become unstable or take in water.

  A tether 72 inches or longer in length must be attached. The attach point must be such that sufficient tension on the tether can be applied while maintaining correct flotation attitude.

- Donning and retention. The means of retaining the life preserver on the wearer must require the wearer to secure no more than one attachment and make no more than one adjustment for fit.

  The time for unassisted donning must be less than 25 seconds, starting with the preserver in its storage packet.

  The time required for assisting a child or another adult in donning must be less than 30 seconds.

  The preserver must be adjustable after donning and in the water.

  Possibility of inadvertent release should be minimized.

  The blood circulation or breathing of wearer must not be adversely affected during use.

- Survivor locator lights must be furnished on each vest (per TSO C-85). The lights must automatically activate upon contact with water.

- Packaging for the preserver must be provided with clear size and usage markings and the means of opening must be simple, obvious, and be accomplished in one operation without tools or excessive force.

- Instructions should be presented pictorially with minimum usage of words and such that they may be read while in the water. Size of marking is also specified.

- Color must be an approved international rescue color.

- Required test and approved federal test methods are outlined: Material strength test, leakage test, overpressure test, and salt spray test are required.

- Inflator tests including required operating force (<15 lb.), pull cord strength (>100 lb.), proof pressure, and mechanical inflation valve specifications are stated.

- Fire protection requirements are stated.

- Donning tests with live subjects are outlined.

C-72C—INDIVIDUAL FLOTATION DEVICES

1. Overview: Applies to individual flotation devices of the kind not covered by TSO C-13, and categorizes flotation devices as inflatable or noninflatable. Inflatable refers to inflation accomplished by release of a compressed gas. Noninflatables typically comprise seat cushions, head rests, arm rests, pillows, or similar aircraft equipment.

2. Requirements:

- Materials must be of a quality which experience and tests have demonstrated to be suitable for the intended use.
- Protection from fungus, corrosion, and fire must be provided.
- Functional temperature range of -40 to +140°F is required
- Donning:

  Design of device, means of inflation, and method of donning should be simple and obvious to the user.

  Means for oral inflation must also be available in the event of failure of the gas cartridge.

  Size should be such that the device should be adaptable for children as well as adults.

  Blood circulation or breathing of the wearer must not be restricted during use.

- Buoyancy requirement—both Type-I and Type-II devices must be capable of providing not less than 14 lb. of force for a period of at least 8 hours.

3. Tests:

- Salt spray test requirements are stated.

- Flame resistance requirements are stated in terms of maximum burn rate (inches per minute) for combustibles or in terms of degree of resistance to burning for noncombustibles. Materials must comply with self-extinguishing fire protection provisions of FAR 25.853(b).

- Test for fire blocking of seat cushions must be conducted in accordance with appendix F, part II of FAR Part 25.

- Buoyancy testing—must take into account extended service use, particularly of noninflatables.

- Temperature test—temperature range of operation must be verified by testing.

C-85—SURVIVOR LOCATOR LIGHTS

1. Overview: Survivor locator lights are required on all life rafts and life preservers including adult, child, and infant types. The standard applies to the light assembly which includes power source, wiring, attachment provisions, and the light proper.

2. Materials, parts, and adhesives used in the lights must conform to the same specifications mentioned in TSO C-13 and TSO C-70 for life preservers and life rafts respectively.

3. Performance: The following performance requirements are listed.

   - Light intensity must be a minimum of one candle measured in all directions of a horizontal plane. For a flashing light, the effective intensity must be greater then the value specified in the TSO.

   - Time of operation over which required intensity is to be provided is equal to eight hours.

   - Attachment provisions must be such that accidental removal is precluded.

   - Moisture penetration must be of such that operation of the device within the limits of the specifications is not hindered.

   - Source of electrical power can be suitable dry cells or immersible water activated batteries.

   - A method of controlling activation of the light must be provided.

4. Required Tests: Tests are required for salt spray resistance, rubber goods strength, light intensity, flame resistance, and water tightness. Required federal test methods, where applicable, are given. Functionality tests to assure compliance with this TSO are also specified.

APPENDIX I—SUMMARY OF TECHNICAL STANDARD ORDER C-70

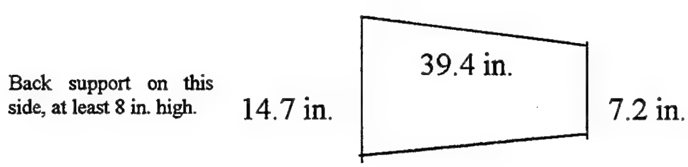
C-70A—LIFE RAFTS (REVERSIBLE AND NONREVERSIBLE)

1. Overview: Describes the standards for reversible and nonreversible life rafts. Life rafts are classified as Type-I (for use in any category aircraft) or Type-II (for nontransport aircraft).

2. Material requirements are separately categorized for nonmetallic and metallic parts. The only requirements for the latter is that they be corrosion resistant. Urethane coated fabric and webbing material must pass specified standards for strength, adhesion, permeability, and seam strength. In addition, material strength and adhesion for the required canopy are stated.

3. Design Requirements can be detailed in the following subclassifications:

   - Capacity—The raft must be of rated capacity of at least 3.6 ft^2 of area per person or of overload capacity (one and a half times rated occupancy) of 2.4 ft^2 of area per person. A raft can be rated by providing an occupant seating space of the following minimum dimensions:



     or by a controlled demonstration meeting detailed criteria specified in this TSO.

   - Buoyancy requirement is based on supporting an average occupant weight of 170 lb.

     Type-I life raft must have at least two independent buoyancy tubes, each with the above mentioned minimum buoyancy force.

     Freeboard must be a minimum of 12 inches at minimum operating pressure or 6 in. if one of the buoyancy tubes has failed. Freeboard is the distance from the surface of the water to the top of the raft.

     Type-II rafts with single tube construction must divide tube into independent flotation chambers.

- Inflation.

  Inflation system for the two chambers must be independent.

  Must not interfere with boarding.

  Must be in accordance with DOT specification 3AA or 3HT.

  Air aspiration, if applicable, must not ingest foreign objects.

  Inflation time or rate should be so as to allow first occupant to start boarding in one minute.

- Canopy is required with the following features:

  Fabric used for construction must be waterproof and resistant to solar penetration.

  Erected canopy must withstand 35-knot winds and 52-knot gusts in open water.

  Provide adequate headroom_and have openings 180 degrees apart.

  Capable of being erected by occupants through clearly posted, simple instructions.

  For reversible rafts, canopy must be installable in either side.

- Capsize resistance must be provided by design.

- Righting aid(s) operable by a single person in the water must be provided on non-reversible rafts.

- Color must an approved international rescue color.

- Placards denoting use of inflation systems, raft equipment, boarding, and righting aids.

- Survivor locator lights which are automatically activated upon contact with the water per TSO C-85 must be placed such that they are visible from any direction by persons in the water.

- Life raft equipment required:

  Boarding aids must be provided 180 degrees apart and be able to handle 500-lb. pull force.

  Lifeline encircling outside periphery must be provided to allow persons in the water to hold onto raft. Must be 3/8 in. in diameter or 3/4 in. wide and be able to support 500 lb.

  Grasp line of similar size and strength as life line must be provided inside raft for occupant support.

  Mooring line at least 20 feet in length such that raft can be attached to a floating aircraft. Release mechanism must be included. Line strength is specified.

  Launching equipment must be comprised primarily of a ripcord and grip with retaining packet. The line attached to the ripcord grip must serve both to retain the raft and to actuate the gas release mechanism. The line must have an operation tension of 20-30 lb.

  Sea anchor to maintain raft at a constant heading relative to the wind and to reduce drift to 2 knots in 217- to 220-knot winds. Sea anchor line must have the specified breaking strength.

  Heaving trailing line of at least 75 foot length and 250 lb. strength attached near the sea anchor attachment.

  Emergency inflation device with minimum displacement of 32 cubic in. per stroke to maintain chamber pressure.

  Accessory case tiedowns to hold any accessories.

  Carrying case with flammability protection, of highly visible color, aviation fuel resistant, chafe protected, with carrying handles, and without conventional zippers.

  Knife. A sheathed, hooked knife secured by a retaining line and attached to the life raft adjacent to point of mooring line attachment.

- Tests required to certify the raft are outlined.

  Material tests along with required applicable federal test methods.

  Test for pressure retention, overpressure, and detailed tests to certify raft function in a fresh water pool with occupants.

  Sea trials including a test to ensure raft can be deployed from aircraft, is seaworthy in 17- to 27-knot winds and 6- to 10-ft waves, portability test, carrying case test, and gas cylinder test.

  Temperature range of operation and inflation rate must be submitted for approval.

NOTE: The TSO does not include all the required equipment to be carried on life rafts. Refer to appendix G for a listing of additional equipment.

APPENDIX J— SUMMARY OF TECHNICAL STANDARD ORDER C-69

C-69—EMERGENCY EVACUATION SLIDES, RAMPS, AND SLIDE/RAFT COMBINATIONS

PART-I

1. Overview: The TSO consists of two parts; Part I covers inflatable emergency evacuation slides and overwing exit ramps. Part II covers inflatable emergency evacuation slide/raft combinations. Part I is then further subcategorized into three types of devices: (a) inflatable evacuation slides suitable for assisting occupants in descending to the ground from floor-level aircraft exits and from aircraft wings, (b) inflatable emergency exit ramp devices suitable for assisting occupants in descending onto aircraft wings from certain overwing exits, and (c) combination inflatable emergency exit ramp and wing to ground slide devices. FAR Part 25 is also referenced as a source of additional requirements that must be considered alongside the contents of this TSO.

2. Material requirements are separately given for metallic and nonmetallic components. Metallic parts must be corrosion resistant or corrosion protected. Urethane coated fabric and webbing must not support fungus growth and must pass specified standards for strength, adhesion, permeability, porosity, seam strength, and flammability. Materials must be chaffing and abrasion resistant.

3. Design requirements:

   - Operation must be simple enough so that brief and easily understood posted instructions can be followed.

   - Temperature range of operation must be -40 to +160°F. Also if installed outside the pressurized cabin, they must be stowable at -65°F.

   - Strength. Device must be capable of withstanding the following requirements when operating at an angle of no more than 30 degrees.

     Evacuee weights of at least 170 lb.

     Evacuation rate of at least one person per minute per lane for a duration not greater than 70 seconds.

     Total load greater than 1,050 lb. per lane.

   - Static resistant design of the fabric and fastenings will be incorporated.

   - Damage resistance. Walking and sliding surfaces must be resistant to puncturing and tearing.

- Usage. Device must be usable as noninflatable slide in case of a puncture or a tear. If multiple cells are used, failure of one must not render the device unusable.

- Length must be such that the device is self-supporting on the ground in both situations where the landing gear is retracted or extended.

- Encumbrances which might be grabbed by evacuees must be minimized.

- Hardware and attachment strength must be at least 1.5 times the highest design load imposed by the overall strength requirements stated earlier.

- Re-entry means, if included in the design., must not interfere with evacuation.

- Use as a flotation device: Slides installed at main deck floor exits must have positive buoyancy and must have a means to disconnect from aircraft so that they can be used as an emergency flotation device. A mooring line longer than 20 feet and of minimum strength of 500 lb. must be provided. It should be possible to easily release moored device from aircraft. A lifeline must also be provided along at least 80 percent of the length of the slide.

- Deployment (from FAR 25.810).

  Means for automatic deployment must be provided. The deployment must start between the interval of time during which the exit door opening mechanism is activated to when it is fully open. The device must be automatically erected in 10 seconds after deployment has begun.

  Wind resistance must be such that the device is deployable and usable under conditions of 25-knot winds directed from the most critical angle.

  Crash conditions: In tests, the device must be deployed and be operable after being subjected to the inertia forces specified in FAR 25.561 (b).

- Inflation.

  Automatic inflation device shall operate in proper sequence so as to ensure safe usage conditions.

  Manual inflation means must also be provided which is neither visible nor presented for use until required.

  Inflation time. After actuation of inflation, the device must be automatically erected in 6 seconds.

  System must be connected and ready for use.

Must be constructed to minimize leakage due to back pressure.

If an air aspirator is used for inflation, the system must be constructed to prevent ingestion of foreign objects.

- Manual inflation actuation controls.

    Red in color with clear instructions for use.

    Visible to an occupant standing at the door and under minimum lighting conditions as stated in FAR 25.561.

    Placed on the right side of the girt looking out of the aircraft, if possible.

    Deployment force must not exceed 30 lb.

    Must not trip or entangle evacuees.

- Extendible length slides.

    The extension must be capable of inflation after the main slide.

    Inflation controls for the extension must be separate from those of the main slide.

- Double lane slides.

    Space must be such that it is possible for two evacuees to slide abreast. If a separator is used, each lane must be at least 20 in. wide. If no divider is used, the minimum width must be 42 inches.

    Must resist adverse twisting or deflecting when subjected to maximum asymmetrical loading under design load conditions.

    A raised divider, if used, must be constructed so as to prevent injury to evacuees.

- Side guards must be provided to prevent evacuees from missing or falling from the device.

- Emergency knife, if provided, must be in a position where it cannot injure evacuees.

- Self illumination means must be automatically activated during deployment. The level of illumination must meet the requirements of FAR 25.812.

- Surface Characteristics. Surface must be such that the device must

  be suitable for use in any weather condition, including rainfall of 1 inch per hour, and

  not erode or deteriorate under normal use.

- Pressure retention. Adequate pressure must be retained in all usage conditions, including those in which

  the device is installed in its most critical angle with respect to buckling,

  the inflation system's initial pressure is at the minimum of its design range, and

  two hundred individuals evacuate at the rate of 1 per second per lane.

- Tests required are

  Overpressure test at 1.5 times the maximum operating pressure.

  Leakage test to show that the pressure does not fall below 50 percent of nominal operating pressure in a period of 12 hours.

  Material tests for aging, tensile and shear strength, tear and puncture strength, adhesion, permeability, hydrolysis conditions, and porosity are given along with approved federal test methods where applicable.

PART-II

Part-II of TSO C-69 lists requirements that pertain to the raft mode operation of the slide/ramp devices. The detailed material and design requirements are as stated in TSO C-70 for life rafts.

The appendix to this order specifies the requirements for radiant heat testing of the materials covered by this TSO. The operation of pressure retaining devices such as slides rafts and ramps can be compromised in situations where a fire may exist. Therefore, this standard outlines the test apparatus and the required performance under prescribed values of the heat flux and the time of application. Briefly, the specimens must be tested in an approved apparatus at heat flux values of 1.5 Btu/ft^2-sec, and the time to failure must be shown to be greater than 90 seconds.